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FIFTH BILLINGS SYMPOSIUM

ON

DISTURBED LAND REHABILITATION

Volume II

Billings Plaza Holiday Inn, Billings, Montana
March 25-30, 1990

CO-CHAIRMEN

Frank F. Munshower Director Reclamation Research Unit Montana State University Bozeman, Montana	Scott E. Fisher, Jr. Biological Scientist Western Technical Center Office of Surface Mining Denver, Colorado

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DISCLAIMER

This publication contains the proceedings of the Symposium on Disturbed Land Rehabilitation. Speakers were asked to submit camera-ready copy for this publication. Because of the schedule for printing, the chairmen were unable to edit the texts and apologize for any errors in the copy or poor reproduction of figures or tables.

Several papers were not received in time to be included in this publication; thus, the lack of conformity between the Agenda of the Symposium and this published proceedings was unavoidable.

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the sponsors.

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Frank F. Munshower
Co-Chairman

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

HAZARDOUS MATERIAL MANAGEMENT: AN INTEGRATED APPROACH

Andrea L. Stomberg[1]

ABSTRACT

Federal and State regulations govern virtually every aspect of industrial material use and disposal. Maintaining control over hazardous materials requires the coordination of purchasing, safety and environmental functions, as well as the education of supervisors and the work force.

At the North American Coal Corporation´s three surface coal mines in North Dakota, an integrated approach to hazardous material handling has been developed. This program involves pre-purchase evaluation of materials, identification of all hazardous materials in use, labeling, and training of employees to properly use and dispose of these materials. Product substitution and waste minimization are also important facets of the program.

While maintaining compliance with environmental, health and safety regulations, this program minimizes worker exposure to hazardous materials, and reduces corporate liability. Important features of, and principal difficulties in implementing, this program are discussed.

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INTRODUCTION

State and Federal hazardous material regulations govern the use and disposal of many commonly used industrial materials, and require the training of personnel exposed to them. Surface coal mines, while exempt from the Occupational Safety and Health Administration's 1910.1200 Hazard Communication standards, are nonetheless subject to state hazard communication rules, and the Mine Safety and Health Administration's (MSHA) vague, but broadly interpreted, air toxics standards. Together, these regulations require knowing what materials are in use, ensuring that exposed individuals are protected and trained, and that spills and wastes are effectively and legally managed.

The North American Coal Corporation's (NACCO) three surface coal mines in North Dakota produce from one to 10 million tons of lignite coal per mine, annually. The mines are relatively simple industrial sites, in that no chemical products are created, and wastes generated are mundane-greases, oils, paints and some solvents. Identification of regulated materials and compliance with a North Dakota state requirement to develop a hazard communication program, including a Material Safety Data Sheet (MSDS) file, was nonetheless a significant undertaking.

Inventory

NACCO's centralized purchasing department maintains a listing of all products that have been routinely ordered. What products are actually present and in use, however, is difficult to assess. Some materials, for various reasons, have never formally entered the purchasing procedure. In order to assess actual materials on site, an inventory was performed under the direction of the supervisors in each work area. All chemicals located in each area were listed. This list was then used by the purchasing department, to develop a cross referenced hazardous material inventory that was designed to indicate if an MSDS was available on site, and if the product was a Resource Conservation and Recovery Act (RCRA) or Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) regulated material.

Because of the similarity of the products used at all three of the North Dakota mines, a master file of all MSDS (about 1500) was compiled and distributed to each site. The file is organized alphabetically by manufacturer. The hazardous material inventory is included with the file, and is cross referenced by stock number, vendor, and product.

MSDS Evaluation

Once most of the MSDS were obtained, it became obvious that, for use, many were deficient. Statements like "use with adequate ventilation", "dispose of in accordance with all applicable regulations" , and other, similarly ambiguous, cautions were frequently encountered. This type of statement raised concerns about NACCO's ability to adequately manage product use.

Because of these concerns, NACCO developed a MSDS review procedure, using National Institute of Occupational Safety and Health, Department of Transportation and Environmental Protection Agency data bases available on a compact disk system. This procedure involved developing a summary sheet listing personal protective device requirements, physical properties, and waste and spill management information for the "worst-case" chemicals present in each product. This information, used to supplement the MSDS provided by the manufacturer, provides more specific guidance than was found to be typically indicated on the MSDS. An industrial hygenist reviewed the summary procedures and indicated in writing that it was a reasonable, defensible method of reviewing MSDS's.

Additionally, a policy was instituted requiring that the MSDS be reviewed prior to product purchase. In this way, hazardous products will be identified. The person requesting a hazardous product is contacted so that substitutes can be evaluated, or required personal protection ordered, and exposed personnel trained.

In order to more fully utilize the hazardous material inventory and available data bases, safety managers requested that the "top 20" most used, most hazardous products at each mine be identified. This was accomplished using the purchasing departments inventory records and the MSDS summary. These products were evaluated for possible substitution, and used as a focus for specific training. Additionally, these MSDS and summary sheets will be reviewed by an industrial hygenist to ensure accuracy. NACCO plans to send additional selected MSDS to an industrial hygenist for review to ensure that the most hazardous products carry adequate warnings.

Database Development

Recently, MSHA proposed regulations governing the use of a number of carcinogenic compounds at mines. This has prompted NACCO to develop a data base file which includes stock number, product name and each chemical and Chemical Abstract Service Registry Number associated with the product. This will enable NACCO to review all products for any specific chemical constituent, including the MSHA carcinogens. This data base will also be useful in developing hazard or chemical-specific training programs, and in identifying and managing hazardous wastes.

Labeling

One further task that will be undertaken is to develop an internal labeling program. Currently, NACCO relies on the product label that is provided by the manufacturer. These labels, however, frequently do not note if the material will be a listed or characteristic hazardous waste, or if it is a reportable material under CERCLA.

Labeling of at least high hazard, high-use materials with regard to RCRA and CERCLA requirements is contemplated. This should simplify waste management and address CERCLA liability concerns. Additional labeling indicating personal protection requirements may eventually be included.

Policy and Procedure

The described programs have been formalized as corporate policy and procedure governing hazardous material management. Having a written policy and specific guidelines approved by mine and corporate management gives creedence to the program. The guidelines can be used in internal audits and reviews to assess compliance.

Although there is and will always be a threat of liability associated with the exposure of personnel to hazardous materials, the program just described is an indication of NACCO's resolve to minimize this risk in a cost effective manner. By involving purchasing, safety and environmental functions in all stages of program development, and utilizing outside experts where necessary, a program with multiple uses and a broad base of support has been developed.

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

EVALUATION OF COPPER MINE TAILINGS USING EPA LEACHING PROCEDURES

John C. Franklin[1] and John A. Riley[1]

ABSTRACT

The U.S. Bureau of Mines investigated three different Environmental Protection Agency (EPA) leaching procedures used to evaluate metal contamination in mill tailings. These procedures were the Toxic Characteristic Leaching Procedure (TCLP), Extraction Procedure Toxic test (EP Tox), and Method 1312 (M-1312). TCLP and EP Tox use acetic acid while M-1312 uses a 60/40 mixture of sulfuric and nitric acids.

Samples from mill tailings from 12 mines located in five different Western states were used in the tests. The data from each mine were compared qualitatively by region and leaching procedure, and then the complete data set was compared statistically by leaching procedure. The results indicated that the three leaching procedures sometimes produced results that differed from each other. If differences were detected, the TCLP usually produced higher concentrations of metals in the leachate than the other two methods.

---

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INTRODUCTION

Substantial public concern has been voiced regarding contamination of water resources by mining and the resulting adverse effects on human health. This concern has prompted EPA to initiate a regulatory development program for the mining industry, which in turn has created a need to predict contamination potential at mine sites.

The leaching procedure being considered as the standard method for determining contaminates leached from soil is the EP Tox (Federal Register, 40 CFR Ch.1, Part 261). This method uses acetic acid in distilled water that has been adjusted to a pH of 5.0. The EP Tox test was primarily designed for use around sanitary landfills where organic waste is present. Mine mill tailings usually contain low levels of both organic and inorganic wastes even though volumes of waste is high.

Two other leaching procedures available but not used by state and Federal regulatory agencies are the TCLP and M-1312 (U.S. Environmental Protection Agency, 1988). TCLP uses acetic acid while M-1312 uses a sulfuric and nitric acid solution. Both tests are designed similarly to EP Tox yet they are different. TCLP contains a fixed amount of acid that has a starting pH of 2.88, whereas EP Tox contains only the amount of acid needed to maintain a pH of 5.0. M-1312 is designed to start at a pH of 5.0, but this procedure incorporates no controls over final pH and uses a sulfuric/nitric acid solution.

The mining industry is concerned about the use of the EP Tox method because some metals, such as lead, are more soluble when associated with the acetate ion than with many other ions. The overall solubility of lead is enhanced by the acetate ion because acetate and lead form a complex ion that shifts the solubility equilibria of most lead compounds in favor of the dissolved species. For example, the Lead Industries Association (American Resources Corporation and Environmental Engineering and Management, 1984) reports that the preferential dissolution of lead by the acetic acid used in the test procedure skews tests for lead.

As a result, the U.S. Bureau of Mines' Spokane Research Center is performing research to determine more effective methods of evaluating contamination potential from metal/nonmetal mines. As a part of this effort, we are examining existing laboratory testing methods to determine what applicability these methods may have in assessing contamination potential. Previous tests (Franklin and Zahl, 1988) compared the EP Tox and TCLP methods using tailings from lead and silver mills. Doepker (Doepker, 1988) reported on data obtained from column leaching procedures using tailings from the same mills.

Analytical Comparisons of Leaching Results

This report examines the results of leaching tests using tailings from 12 copper mines located in five Western states. At some mines, secondary metals were also recovered. At least one sample from each mine was leached using all three EPA methods. Multiple samples were taken at different locations and at different depths in the same waste pile. A pairwise statistical comparison was made among multiple samples from the same mills by leaching procedure. Organic and volatile materials were excluded from these experiments because they are of little concern in mine tailings.

A Perkin-Elmer ICP,* which can analyze up to 27 different elements, was used for the analyses. Some of these elements were analyzed just to obtain regional comparisons and did not add any significant information to this report, while others were below detection limits for the ICP. The results are reported by region of the country. Some regions had several mines whereas others contained only one mine (table 1). All five regions are located west of the Mississippi River. The mineralogy of most of the regions is described by Doepker and O'Connor (1990).

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*Reference to specific equipment or trade names does not imply endorsement by the Bureau of Mines.

Table 1.--Regions Sampled for EPA Leaching Test

Region	Location	No. of mines	No. of samples
1.......	Northwestern	1	4
2.......	Northern	1	1
3.......	Central	6	8
4.......	Western	2	6
5.......	Southwestern	1	9

Table 2 shows test results on tailings from an inactive copper/gold mine that has been closed for some time. All three leaching procedures were used. Run 52 came from a small waste pile isolated from the main pond. All analyses indicated that this pond had significantly higher metal concentrations than the other three samples taken from the main tailings area. Since the mill is not in operation, there is no positive explanation as to why this pond produced different results than the main pond. The TCLP test results usually show higher concentrations of metals (except silver) than shown by the other methods. Silver concentrations were higher when M-1312 was used.

TABLE 2. Copper Mine Data, Region 1, milligrams per liter.

RUN	TRT	AG	AL	AU	BA	CD	CR	CU	FE	K	MG	NA	PB	SE	SI	SR	S	ZN
R2	1	24.030	24.78	0.00	0.019	0.173	0.007	32.607	4.244	0.27	6.58	0.00	0.03	0.20	1.406	0.037	83.94	14.643
R2	2	31.499	37.63	0.00	0.012	0.200	0.016	39.537	11.083	0.82	7.19	0.00	0.04	0.14	2.388	0.040	93.84	16.550
R2	3	50.530	35.92	0.00	0.032	0.192	0.014	38.300	11.003	0.89	7.05	0.00	0.00	0.15	3.040	0.039	91.56	15.977
R2	4	90.043	27.97	0.00	0.012	0.193	0.003	37.683	3.998	0.00	5.49	0.00	0.00	0.23	1.233	0.014	87.91	15.957
R3	1	53.070	1.77	0.00	0.104	0.000	0.001	0.338	3.407	0.00	6.22	0.00	0.00	0.17	2.466	0.070	18.53	10.753
R3	2	52.857	0.62	0.00	0.054	0.000	0.000	0.238	1.589	0.08	5.18	0.00	0.00	0.27	2.690	0.056	18.14	8.057
R40	1	0.000	10.81	0.01	0.036	0.000	0.010	1.210	3.260	0.50	11.63	0.23	0.08	0.30	0.000	0.075	77.00	0.410
R40	2	0.000	12.48	0.00	0.283	0.000	0.010	0.350	6.680	0.20	11.03	0.33	0.03	0.20	0.000	0.078	71.60	0.830
R40	3	0.000	12.90	0.00	0.109	0.000	0.000	0.560	6.660	0.30	11.90	0.37	0.00	0.40	0.000	0.079	76.00	0.370
R40	4	0.000	10.35	0.00	0.013	0.000	0.010	0.750	2.400	0.30	11.30	0.24	0.09	0.20	0.000	0.074	75.60	6.120
R52	1	0.010	80.32	0.01	0.000	1.070	0.170	272.390	46.890	0.60	37.87	0.41	0.20	0.00	1.790	0.118	556.10	141.010
R52	2	0.030	96.27	0.00	0.000	1.180	0.420	290.640	75.280	0.80	42.17	0.70	0.20	0.00	1.620	0.140	635.00	156.520
R52	3	0.010	90.12	0.00	0.000	1.150	0.420	288.640	75.780	0.60	41.82	0.63	0.14	0.00	1.650	0.131	607.50	155.100
R52	4	0 000	96.60	0.00	0.000	1.250	0.200	309.930	54.630	0.30	45.64	0.47	0.14	0.00	1.720	0.134	628.30	173.800

Data were available from only one mine in the second region (table 3). As in the first region, the TCLP results were usually the highest; however, no elements were as concentrated as in the region 1 mine.

Region 3 results from six mines are reported in table 4. Some of these mines are no longer in production. As before, the TCLP method usually produced the highest concentrations of metals. One mine had high lead concentrations using the EP Tox and TCLP methods, but low lead concentrations using M-1312. All three leaching methods produced high concentrations of silver and copper when samples from one particular mine were analyzed.

Table 3. Copper Mine Data, Region 2, milligrams per liter

RUN	TRT	AG	AL	AU	BA	CD	CR	CU	FE	K	MG	NA	PB	SE	SI	SR	S	ZN
R19	1	0	0.31	0.10	0.152	0	0.01	3.94	1.34	16.9	10.53	28.43	0.04	0.0	2.44	0.407	27.6	0.20
R19	2	0	1.51	0.04	0.201	0	0.01	8.04	6.22	19.4	12.76	28.49	0.07	0.3	3.80	0.424	25.7	0.28
R19	3	0	1.75	0.11	0.211	0	0.01	9.05	6.71	21.0	13.66	33.28	0.13	0.0	4.40	0.489	34.8	0.31
R19	4	0	0.21	0.00	0.020	0	0.01	0.04	0.72	8.3	4.47	28.76	0.03	0.0	1.80	0.199	35.0	0.02

TABLE 4. Copper Mine Data, Region 3, milligrams per liter

RUN	TRT	AG	AL	AU	BA	CD	CR	CU	FE	K	MG	NA	PB	SE	SI	SR	S	ZN
R1	1	75.990	2.25	0.00	0.000	0.006	0.004	11.203	8.851	1.88	37.27	0.24	0.01	0.16	1.724	0.094	157.57	2.982
R1	2	73.720	6.09	0.00	0.000	0.002	0.004	13.957	13.933	2.10	40.33	0.17	0.02	0.33	1.900	0.107	163.00	3.304
R1	3	22.227	5.95	0.00	0.000	0.001	0.007	14.523	13.200	2.29	37.77	0.00	0.01	0.31	1.839	0.101	155.43	3.009
R1	4	148.610	2.47	0.00	0.000	0.002	0.005	12.333	9.400	1.51	35.89	0.00	0.00	0.12	1.342	0.095	157.07	3.022
R18	1	0.000	0.20	0.01	0.098	0.010	0.000	0.730	3.840	1.90	0.84	0.46	0.11	0.00	1.890	0.034	8.00	4.030
R18	2	0.010	0.44	0.01	0.137	0.020	0.000	1.890	1.420	1.10	1.01	0.06	0.00	0.10	1.240	0.029	6.40	6.790
R18	3	0.010	0.39	0.02	0.130	0.020	0.000	1.920	1.400	0.90	0.96	0.02	0.10	0.10	1.120	0.027	6.10	6.930
R18	4	0.000	0.08	0.01	0.058	0.010	0.000	0.520	2.180	0.80	0.74	0.35	0.06	0.20	1.000	0.024	7.20	3.530
R20	1	0.000	0.31	0.10	0.059	0.010	0.010	3.160	1.150	6.60	3.50	4.05	0.01	0.00	5.440	0.640	8.50	1.010
R20	2	0.000	1.05	0.15	0.098	0.010	0.010	9.360	7.690	7.40	4.27	4.20	0.18	0.10	7.330	0.710	8.00	1.540
R20	3	0.000	1.00	0.10	0.092	0.010	0.020	9.140	7.850	7.10	3.83	3.98	0.19	0.00	6.430	0.681	8.60	1.460
R20	4	0.000	0.25	0.00	0.007	0.000	0.010	0.050	0.760	4.50	1.38	4.88	0.05	0.00	4.370	0.259	17.50	0.020
R21	1	0.000	0.38	0.10	0.068	0.010	0.010	3.630	2.300	6.60	3.94	4.23	0.01	0.00	6.480	0.636	9.00	1.100
R21	2	0.000	1.06	0.12	0.102	0.010	0.020	8.740	9.150	7.70	3.99	4.41	0.24	0.10	7.690	0.700	8.90	1.500
R21	3	0.000	1.23	0.18	0.117	0.010	0.020	9.570	9.840	8.90	4.88	5.23	0.32	0.30	9.470	0.815	9.90	1.660
R21	4	0.000	0.17	0.01	0.010	0.000	0.010	0.050	0.840	4.60	1.93	4.29	0.04	0.00	4.810	0.320	27.10	0.030
R22	1	0.000	0.32	0.04	0.066	0.020	0.000	5.110	0.790	9.10	5.48	7.66	0.05	0.00	10.310	0.762	12.60	2.310
R22	2	0.000	1.97	0.13	0.131	0.030	0.020	17.030	19.910	10.70	7.23	9.07	0.35	0.00	14.450	0.933	13.50	4.080
R22	3	0.000	1.82	0.06	0.127	0.030	0.020	15.790	22.740	10.10	6.58	9.31	0.31	0.10	13.740	0.905	12.70	3.870
R22	4	0.000	4.32	0.00	0.032	0.000	0.010	1.460	4.310	7.80	2.62	7.45	0.05	0.00	18.610	0.180	11.40	0.510
R25	1	0.010	0.01	1.24	0.533	0.260	0.010	1.900	1.360	2.20	62.58	0.23	14.95	0.00	15.650	0.065	6.20	88.060
R25	2	0.020	0.76	3.12	0.740	0.210	0.020	4.440	11.110	2.50	172.44	0.46	27.41	0.20	15.570	0.098	8.00	88.480
R25	3	0.020	0.75	3.08	0.740	0.210	0.020	4.420	10.620	2.30	175.00	0.44	27.49	0.00	15.560	0.098	8.10	89.400
R25	4	0.000	0.00	0.00	0.159	0.000	0.010	0.000	0.490	0.60	1.94	0.25	0.08	0.00	1.090	0.012	4.50	0.370
R26	1	0.000	0.09	0.15	1.134	0.030	0.010	0.350	0.470	42.30	58.36	1.57	0.07	0.00	10.900	1.236	27.90	0.930
R26	2	0.000	0.20	0.00	0.954	0.020	0.010	0.080	0.510	42.50	50.55	1.40	0.05	0.10	10.740	1.042	22.00	0.310
R26	3	0.000	0.40	0.04	0.961	0.010	0.010	0.090	0.650	42.90	50.30	1.39	0.00	0.20	11.890	1.037	21.30	0.450
R26	4	0.000	3.26	0.00	0.094	0.000	0.000	0.040	3.510	21.30	6.85	3.22	0.02	0.00	15.720	0.055	5.80	0.120
R42	1	0.000	0.07	0.07	0.035	0.080	0.000	0.060	0.460	1.40	29.07	0.21	0.22	0.00	0.000	0.023	42.50	37.630
R42	2	0.000	0.68	0.23	0.055	0.280	0.010	0.650	12.370	1.50	66.22	0.48	0.78	0.00	0.000	0.047	44.00	69.410
R42	3	0.000	0.72	0.27	0.066	0.280	0.010	0.680	12.560	1.60	67.70	0.73	0.86	0.30	0.000	0.051	44.30	71.880
R42	4	0.000	0.08	0.00	0.009	0.030	0.000	0.020	0.310	0.80	13.12	0.54	0.01	0.30	0.000	0.012	46.30	1.970

Region 4 had two copper mines (table 5). All three methods resulted in high concentrations of copper (the highest from any region), but differences among the three methods were not as great as the differences among mine samples from the other regions.

TABLE 5 Copper Mine Data, Region 4, milligrams per liter

RUN	TRT	AG	AL	AU	BA	CD	CR	CU	FE	K	MG	NA	PB	SE	SI	SR	S	ZN
R16	1	0.000	2.56	0.070	0.099	0.000	0.000	0.850	6.150	9.30	6.89	13.94	0.06	0.10	8.910	1.935	91.10	0.140
R16	2	0.000	5.94	0.060	0.144	0.000	0.000	1.830	17.010	13.00	8.45	17.05	0.04	0.00	13.820	2.179	95.30	0.170
R16	3	0.000	5.73	0.070	0.139	0.000	0.010	2.000	17.690	11.30	9.18	16.98	0.00	0.00	13.390	2.222	95.60	0.180
R16	4	0.000	0.08	0.010	0.061	0 000	0.000	0.020	0.140	8.40	2.92	15.22	0.08	0.00	4.740	1.544	123.90	0.020
R17	1	0.000	1.47	0.070	0.090	0.000	0.000	0.630	1.850	9.50	5.53	8.03	0.00	0 10	8.590	1.792	94.20	0.100
R17	2	0.000	6.75	0.060	0.145	0.000	0.010	2.660	16.750	13.80	8.20	8.67	0.00	0.20	18.790	1.957	99.10	0.180
R17	3	0.000	6.62	0.070	0.139	0.000	0.000	2.630	15.490	13.90	8.15	8.34	0.05	0.10	18.040	1.903	97.20	0.190
R17	4	0.000	0.50	0.010	0.051	0.000	0.000	0.050	0.800	8.00	2.82	7.34	0.00	0.20	5.420	1.176	126.50	0.020
R4	1	0.006	1.93	0.186	0.000	0.012	0.001	37.687	0.951	11.67	25.38	35.36	0.05	0.81	2.308	0.116	149.43	3 536
R4	2	0.006	5.81	0.166	0.000	0.011	0.010	64.033	10.653	17.08	27.47	37.26	0.02	0.61	3.946	0.143	143.93	4 222
R4	3	0.007	5.73	0.183	0.000	0.012	0.010	63.940	10.310	15.72	27.74	35.16	0.01	0.81	3.590	0.141	149.13	3.997
R4	4	0.005	1.64	0.151	0.000	0.013	0.001	37.527	0.754	12.00	24.59	34.81	0.05	0.72	1.474	0.108	146.43	3 442
R5	1	0.005	12.49	0.044	0.000	0.002	0.007	10.540	1.919	1.12	37.03	2.04	0.04	0.82	0.923	0.070	116.97	0.738
R5	2	0.004	17.67	0.060	0.000	0.003	0.011	11.820	3.862	1.69	38.42	2.45	0.07	0.87	0.804	0.095	120.17	0.757
R5	3	0 004	17.61	0 062	0.000	0.003	0.016	11.893	3.585	1.71	38.22	2.38	0.01	0.52	0.691	0.100	117.10	0 731
R6	1	0 004	11.13	0.130	0.000	0.004	0.007	12.977	1.207	0.91	49.38	5.22	0.00	0.52	1.134	0.086	154 77	1.122
R6	2	0.004	18.25	0.126	0.000	0.004	0.020	15.600	3.365	1.15	52.81	5.50	0.03	0.70	0.988	0.113	149.43	1.176
R6	3	0.005	18.12	0.132	0.000	0.004	0.009	15.497	3.021	0.95	48.58	5.76	0.05	0.60	0.963	0.107	140.43	1.145
R6	4	0.007	12.70	0.100	0.000	0.003	0.007	14.730	1.063	0.95	54.56	5.77	0.06	0.87	1.003	0.088	161.83	1.243
R7	1	0.003	1.85	0.071	0.032	0.003	0.004	30.023	1.145	6.42	14.96	13.14	0.00	0.00	1.558	0.077	120.50	2.052
R7	2	0.000	5.53	0.096	0.012	0.005	0.010	41.107	12.567	10.17	15.59	12.98	0.00	0.40	2.801	0.090	112.37	2 139
R7	3	0.000	5.67	0.093	0.007	0.004	0.012	42.683	14.000	9.67	15.81	13.09	0.01	0.04	2.475	0.091	119 23	2 206
R7	4	0.000	1.75	0.064	0.026	0.005	0.006	28.837	1.073	6.21	14.62	11.77	0.00	0.43	1.202	0.070	121.17	1 882

The results reported in table 6 were from samples from four different tailings ponds at one mine in Region 5. Samples were taken from two different depths and different ends of the ponds. The results for Region 5 are similar to those for Region 4 in that the differences among the results of the three methods were not as great as they were from the other three regions. The TCLP method produced the highest concentrations for nearly every element analyzed, with copper showing the highest concentration of all elements tested.

Statistical Comparison of Leaching Results

The purpose of this work was to determine if the various leaching procedures yielded different metal concentrations from the same tailings sample. There was no desire to make a global comparison of all samples because of inherent mine-to-mine variability.

A pairwise comparison procedure was used to evaluate whether a significant difference existed in leachate metal concentrations as a result of subjecting aliquots of a tailings sample to different leaching procedures. This technique provides a method for comparing each sample to itself.

TABLE 6. Copper Mine Data, Region 5, milligrams per liter

RUN	TRT	AG	AL	AU	BA	CD	CR	CU	FE	K	MG	NA	PB	SE	SI	SR	S	ZN
T1	1	0.001	1.37	0.009	0.000	0.063	0.000	19.457	1.311	3.34	2.28	0.69	0.03	0.07	1.985	0.053	116.00	3.889
T1	2	0.001	2.55	0.018	0.017	0.083	0.003	34.977	9.384	3.87	2.58	0.81	0.05	0.09	2.943	0.074	104.20	5.158
T1	3	0.001	2.58	0.008	0.034	0.077	0.034	37.110	9.750	3.89	2.72	0.73	0.00	0.25	2.938	0.078	108.40	5.195
T1	4	0.000	0.92	0.011	0.000	0.071	0.025	19.267	0.866	3.24	2.22	0.61	0.00	0.41	1.218	0.058	109.60	4.044
T2	1	0.000	0.60	0.006	0.008	0.054	0.031	8.022	0.843	7.98	2.41	2.27	0.02	0.55	8.050	0.151	92.30	1.140
T2	2	0.029	4.85	0.005	0.051	0.101	0.048	49.333	20.587	10.07	4.66	3.22	0.08	0.30	17.530	0.213	87.10	2.637
T2	3	0.001	4.93	0.003	0.054	0.100	0.042	49.050	20.210	10.12	4.67	2.45	0.12	0.17	17.713	0.215	83.80	2.596
T2	4	0.000	6.18	0.000	0.037	0.003	0.027	0.885	1.972	8.85	2.13	2.23	0.01	0.09	15.947	0.116	94.20	0.106
T3	1	0.000	0.53	0.017	0.022	0.084	0.031	17.253	1.344	8.74	4.25	3.95	0.00	0.41	4.646	0.129	181.60	3.093
T3	2	0.003	4.10	0.027	0.026	0.163	0.036	49.700	22.210	10.58	7.64	4.10	0.02	0.06	11.800	0.182	211.00	6.479
T3	3	0.001	4.02	0.035	0.021	0.200	0.036	52.847	25.153	10.38	8.48	3.43	0.07	0.01	12.973	0.174	242.70	8.495
T3	4	0.000	0.44	0.031	0.025	0.174	0.026	20.543	1.171	7.92	6.96	3.18	0.04	0.46	5.537	0.141	285.20	6.338
T4	1	0.000	60.85	0.081	0.000	0.032	0.112	57.817	36.420	0.55	36.06	0.98	0.00	0.00	1.627	0.036	282.50	2.550
T4	2	0.000	57.89	0.081	0.000	0.030	0.119	55.167	44.090	0.00	34.15	0.40	0.00	0.00	1.123	0.026	267.80	2.357
T4	3	0.000	56.23	0.072	0.000	0.028	0.115	53.937	42.140	0.00	33.02	0.50	0.03	0.00	1.181	0.029	260.80	2.313
T4	4	0.000	46.24	0.060	0.000	0.027	0.081	47.410	26.923	0.00	28.63	0.33	0.00	0.00	1.022	0.022	229.10	1.988
T5	1	0.000	1.13	0.006	0.000	0.062	0.000	18.350	0.414	3.37	1.73	0.84	0.00	0.00	4.546	0.071	17.50	1.396
T5	2	0.000	2.51	0.007	0.000	0.097	0.004	47.817	12.840	3.98	2.63	1.01	0.15	0.00	8.514	0.103	20.50	2.512
T5	3	0.000	2.34	0.007	0.000	0.090	0.000	43.690	11.460	3.87	2.62	2.02	0.13	0.00	8.150	0.097	18.90	2.332
T5	4	0.000	0.54	0.007	0.000	0.015	0.000	0.552	0.127	1.68	1.05	1.17	0.00	0.00	1.611	0.047	16.00	0.298
T6	1	0.000	0.65	0.010	0.000	0.039	0.000	5.608	0.143	4.68	2.10	2.07	0.00	0.00	5.490	0.083	24.20	0.839
T6	2	0 000	4.01	0.019	0.000	0.079	0.011	33.500	20.437	6.90	3.80	2.12	0.05	0.00	13.820	0.141	22.00	2.940
T6	3	0.000	0.44	0.007	0.000	0.018	0.000	0.499	0.132	2.39	1.25	0.83	0.00	0.00	1.761	0.056	13.40	0.341
T6	4	0.002	2.06	0.002	0.000	0.003	0.000	0.341	0.423	4.72	1.88	1.99	0.00	0.00	6.697	0.069	23.60	0.102
T7	1	0.000	0.50	0.008	0.023	0.035	0.000	5.803	1.151	6.80	1.54	1.81	0.00	0.11	4.632	0.093	18.07	0.924
T7	2	0.000	3.50	0.014	0.088	0.075	0.004	49.983	10.713	8.03	3.02	1.71	0.16	0.21	11.147	0.154	19.21	2.389
T7	3	0.000	3.48	0.011	0.098	0.078	0.003	50.527	10.507	7.86	3.19	1.76	0.17	0.14	11.157	0.153	17.90	2.364
T7	4	0.000	0.66	0.005	0.014	0.007	0.000	0.204	1.670	5.39	1.51	1.49	0.03	0.22	3.213	0.078	19.60	0.172
T8	1	0.000	1.07	0.007	0.034	0.040	0.000	12.543	1.269	6.34	1.73	1.24	0.07	0.32	5.509	0.094	14.14	1.115
T8	2	0.000	3.08	0.011	0.103	0.066	0.000	43.290	9.827	6.88	2.73	1.41	0.13	0.17	9.862	0.126	13.16	2.266
T8	3	0.000	0.48	0.004	0.009	0.005	0.000	0.148	1.112	4.79	1.28	1.16	0.04	0.02	2.840	0.059	13.08	0.198
T8	4	0.000	3.01	0.012	0.105	0.065	0.002	43.843	10.090	6.92	2.80	1.28	0.13	0.00	9.634	0.126	12.48	2.288
T9	1	0.000	0.37	0.001	0.027	0.057	0.000	1.698	1.185	6.59	2.00	1.83	0.02	0.07	6.878	0.122	18.01	0.978
T9	2	0.000	4.68	0.011	0.130	0.164	0.023	44.397	21.697	9.73	4.87	2.05	0.19	0.21	17.357	0.200	17.87	3.587
T9	3	0.000	4.90	0.011	0.150	0.165	0.028	47.663	22.453	10.54	5.26	2.20	0.14	0.18	18.820	0.217	17.72	3.672
T9	4	0.001	0.36	0.005	0.015	0.008	0.000	0.379	1.345	7.07	1.70	1.99	0.03	0.07	5.540	0.102	24.00	0.144

The null hypothesis is that $\overline{X}_1 = \overline{X}_2$ or, equivalently, $\overline{X}_1 - \overline{X}_2 = 0$. Therefore, the difference between the concentrations of an element in the leachate from two tests is determined and evaluated to see if the difference is significantly greater or less than zero. Twenty-eight observations of the concentrations of 17 elements were used. Sulfur concentrations were total sulfur as determined on an ICP. No sulfur speciation analyses were conducted. Only those elements whose mean was greater than 10 times the detection limit of the ICP were retained for the analysis because the accuracy of the ICP is poor near its detection limit.

Table 7 presents the elements and the results of the statistical comparisons. The algebraic sign of detected significant differences is provided to indicate whether the TCLP resulted in higher or lower concentrations than the other methods, based on the overall comparison of 28 samples for a given element. A positive sign in table 7 indicates that the TCLP resulted in higher leachate concentrations than the other method, and a negative sign indicates lower concentrations from the TCLP. A significance level of 0.05 was chosen, but this figure should be used only for diagnostic purposes rather than as an absolute because multiple comparisons were conducted.

Table 7.--Significant difference between leaching tests.

Element	TCLP versus EP Tox	TCLP versus M-1312
Cu..........	+	+
Ag..........	No	No
Al..........	+	+
Au..........	No	No
Ba..........	+	+
Ca..........	No	No
Fe..........	+	+
K...........	+	+
Mg..........	No	No
Mn..........	No	No
Na..........	+	No
Pb..........	No	No
P...........	+	+
Si..........	+	+
Sr..........	+	+
Zn..........	+	No
S (total)...	No	-

The results of the statistical comparison indicated that repeatable results could be expected, and that differences in leachate concentrations resulted from different leaching methods. Replicates of the TCLP were run to determine if the laboratory procedures produced repeatable results. No differences were found, indicating that the laboratory procedures were repeatable. The first column in table 7 represents a comparison of EP Tox with TCLP. The concentrations of copper, aluminum, barium, iron, potassium, sodium, phosphorous, silicon, strontium, and zinc were found to be different between the two tests. The TCLP produced higher concentrations overall than the EP Tox for all elements. The second column represents a comparison of M-1312 with TCLP. Copper, aluminum, barium, iron, phosphorus, silicon, strontium, zinc, and sulphur exhibited a difference in this comparison. The TCLP produced leachate concentrations higher than M-1312 for all elements except sulfur.

Thus, the results of the comparisons were as follows. If differences were detected, the TCLP always produced concentrations greater than the EP Tox based on comparisons of all 28 samples. This was predictable because more acetic acid usually is used in the TCLP than in the EP Tox. Again, if differences were detected, the TCLP produced concentrations greater than M-1312 for all elements except sulfur. This may be influenced by the sulfuric acid used to make the leachant for M-1312. Because TCLP consistently yielded higher leachate concentrations than either of the other procedures, the results of the TCLP should be interpreted as a worst-case scenario, rather than an accurate indication of probable leachate characteristics.

Several elements yielded no differences among the tests. At least two possibilities exist for the failure to detect differences: 1) the leaching procedures actually do produce comparable results or 2) the tailings contained little or none of the elements in question. The failure to detect differences in lead concentrations, as a function of leaching method for example, is probably due to the composition of the tailings rather than a lack of real differences among procedures. The lack of difference in lead concentrations was due to the fact that the leachates from all but two samples (R25 and R42) had little or no detectable lead. Thus, the failure to detect differences in this comparison is inconclusive. However, a visual examination of the data from the samples containing significant amounts of lead suggest that acetate-based procedures do result in much higher lead leachate concentrations than M-1312. More research with samples having elevated lead levels in the tailings is needed to test this hypothesis.

Conclusions

Significant differences in leachate concentrations are found as a function of leaching method used.

The TCLP consistently yields higher leachate concentrations than either of the other methods.

The failure to detect significant differences of some metals, notably lead, may be a function of very low concentrations of those elements in the tailings, rather than the existence of similar leachate characteristics. Additional evaluation is needed using waste samples that contain significant amounts of a given element.

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Soil Geochemistry of Lime-Amended Sulfide Mining Waste[1]

by
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Abstract

The Silver Bow Creek Superfund site is a large mining waste area where degradation of surface water, groundwater, and air quality has resulted from deposition of tailings and mine waste along the alluvial floodplain. One component of the Silver Bow Creek Remedial Investigation and Feasibility Study (RI/FS) was to develop innovative cost-effective remedies for in-situ *treatment of tailings deposited in the floodplain of Silver Bow Creek. Named the Streambank Tailings and Revegetation Study, STARS has focused on use of chemical amendments to neutralize acidity and to reduce the potential mobility of heavy metals.*

A series of laboratory columns tests were conducted to test a variety of chemical amendments for their effectiveness in neutralizing acidity and in reducing mobility of cadmium, copper, and arsenic. Chemical amendments were collected where possible from local sources and included a number of relatively low-cost by-product wastes. Amendments selected included those with 1) acid-neutralizing capacity, 2) available phosphorus, 3) soluble calcium, 4) decomposable organic matter, and 5) other fixation agents (zeolites, and ferric sulfate). Solubility of cadmium in treated waste was reduced by 2.5 orders of magnitude compared to the untreated waste. Levels of soluble copper were reduced by 3.5 orders of magnitude. Finally, arsenic mobility was unchanged in treated samples compared to the control.

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INTRODUCTION

Site History

Mining began in the Butte, Montana area with the discovery of placer gold in Silver Bow Creek in the summer of 1864. Silver was mined extensively in the 1870's, but by 1881, silver was less important as Butte became one of the nations prominent copper mining centers. By 1915, Anaconda Copper Mining Company led the industry, but in 1980, due to a depressed copper market, Anaconda closed all underground mines and continued active mining only in the Berkeley Pit (established in 1955). In 1977, Anaconda became a subsidiary of Atlantic Richfield Company (ARCO). ARCO closed the Berkeley Pit in 1982 and the East Berkeley Pit in 1983. In addition to mining, various ore processing facilities also operated in the Butte area. The first two smelters were erected in 1874 to smelt gold and silver. Ten years later, a copper smelter was built in the town of Anaconda, 27 miles west of Butte. The Anaconda Smelter was moved to a new location in the city and operated from 1903 to 1980.

Over 100 years of continuous mining related activities have altered the area's natural environment. Early mining, milling, and smelting wastes were dumped directly into Silver Bow Creek and transported downstream. Silver Bow Creek originates north of Butte, Montana, and is a major tributary to the upper Clark Fork River. Mill tailings and other mining wastes in and near the creek contaminate downstream areas with potentially toxic elements including: arsenic, cadmium, copper, lead, iron, and zinc. These elements and others were present in the mine ore and remain as by-products of the milling and smelting processes. Silver Bow Creek continued to receive raw mining and milling wastes until 1972, when a treatment plant was added to the Weed Concentrator in Butte.

Several Superfund sites have been established in the Clark Fork River Basin due to the complexity of the mine waste contamination. The Silver Bow Creek Site, the largest designated Superfund site in the United States, extends from the uptown portion of Butte, Montana downstream to the Milltown Reservoir near Missoula, Montana.

Streamside Tailings Operable Unit

Air, soil, and surface and ground waters have been contaminated from tailings and other mining waste deposited in the Silver Bow Creek channel and floodplain. Several million yards of mining wastes are in the floodplain of Silver Bow Creek. Remediation of these wastes is the focus of the RI/FS on the Streamside Tailings operable unit of the Silver Bow Creek investigation. Sulfide oxidation in mine wastes increases acidity which increases the solubility of most metals. Streambank tailings are eroded by wind and water. As water percolates through or flows across the barren streambank mine wastes, metals are leached into ground and surface waters. Water evaporating from the land surface leaves a residue of metal-enriched salts which can degrade air quality. A field study was initiated in 1986 to test liming and revegetation as a remedial method for streambank tailings area. The soil pH of limed tailings (up to 25 tons per acre of lime added) remained below 5.5, even three years after lime application.

The streambank tailings and revegetation study (STARS) was initiated in 1987 to develop low cost, innovative remedial measures for clean-up of portions of the streamside tailings operable unit. The STARS project was divided into three components:

> Phase I: Bench-scale soil column/greenhouse treatability studies designed to develop and test ameliorative treatments.
>
> Phase II: Pilot-scale treatability studies which included field implementation of the remedial options designed in Phase I.
>
> Phase III: Field monitoring program to evaluate the response of the wastes to the ameliorative treatments. This response will be evaluated on the basis of reduced leachate quantity and abating metal flux to surface and ground water.

The purpose of Phase I of STARS was to test chemical and organic amendments in the laboratory to see if metal solubility and phytotoxicity could be reduced. Adding chemical amendments and establishing vegetation should reduce leachate to ground water, contaminated runoff to surface water, and fugitive dust by chemically fixing and neutralizing contaminants, reducing leachate to ground water due to transpiration, and protecting the soil surface with vegetative cover. A portion of phase I focused on laboratory development of suitable soil amendments to raise soil pH and reduce soluble and plant-available metal concentrations.

LABORATORY STUDY METHODS

Column Apparatus

A series of laboratory column studies was conducted to evaluate the use of chemical and organic amendments for reducing metal solubility in mine waste samples. A column test method was designed to simulate field conditions typical of unsaturated streambank tailings. Tempe Cells (Figure 1, produced by Soil Moisture Equipment Company, Santa Barbara, CA) were used for the column studies. They consist of an air-tight chamber with a porous ceramic plate at the base (ceramic used had a 1 bar bubbling pressure). A soil-water mixture is placed in the cell and the assembly is pressurized. As pressure increases, soil pore water is forced out of the soil slurry through the ceramic plate. Hence, unsaturated soil conditions are maintained.

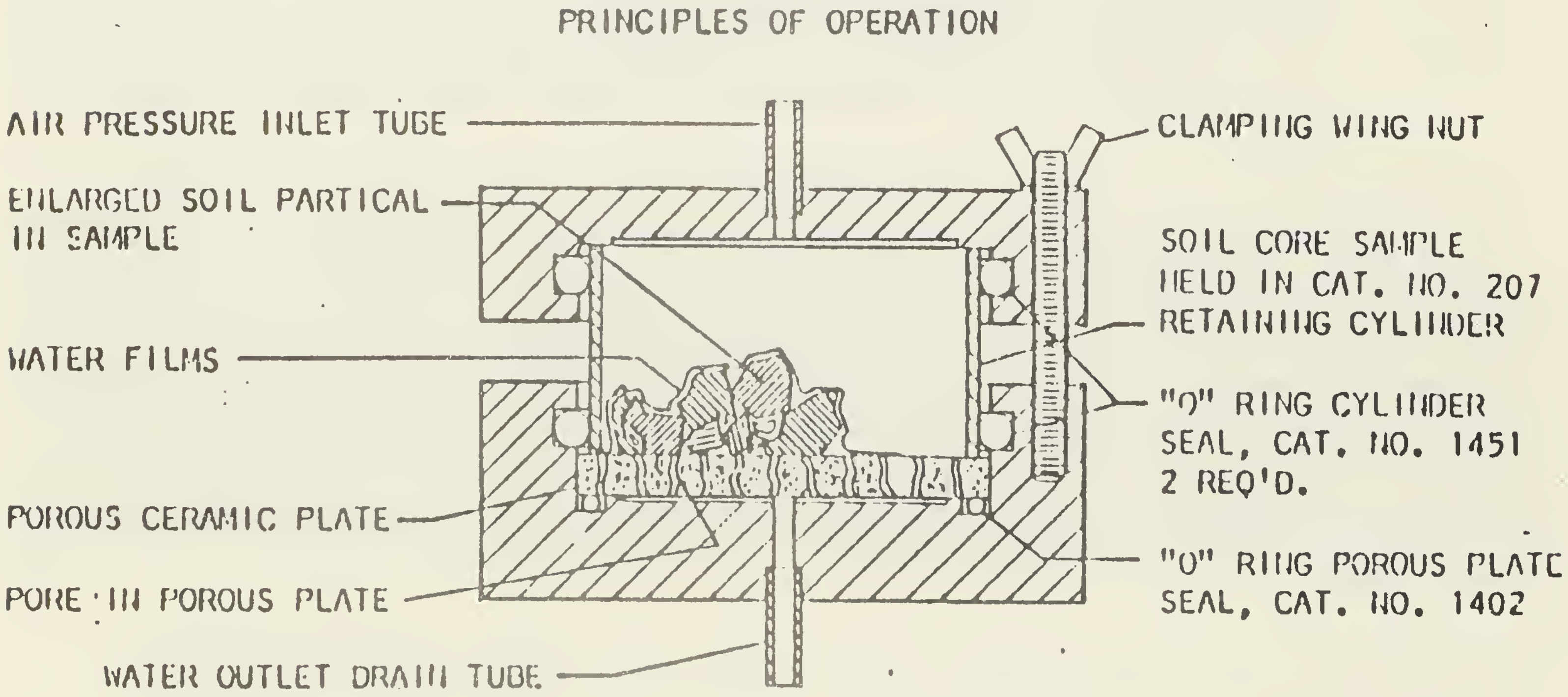

PRINCIPLES OF OPERATION
AIR PRESSURE INLET TUBE
ENLARGED SOIL PARTICAL IN SAMPLE
WATER FILMS
POROUS CERAMIC PLATE
PORE IN POROUS PLATE
WATER OUTLET DRAIN TUBE
CLAMPING WING NUT
SOIL CORE SAMPLE HELD IN CAT. NO. 207 RETAINING CYLINDER
"O" RING CYLINDER SEAL, CAT. NO. 1451 2 REQ'D.
"O" RING POROUS PLATE SEAL, CAT. NO. 1402

Figure 1. Schematic cross-section of a Tempe cell column assembly.

Based on the results of a number of preliminary column tests, standardized column test procedures were developed;

- Column tests were run in batch mode, where 1) the soil water content was adjusted to the saturation percentage, 2) pressure was increased to 0.2 bars, and 3) the system was allowed to drain until equilibrium was reached (about 30 minutes);

- to simulate oxidizing field conditions, the soil slurry was manually stirred after adding water between leach cycles;

- 300 grams of soil (dry weight basis) was used. Soil and amendment material were mixed dry to facilitate complete contact of amendments with soil;

- amended samples were allowed to equilibrate for 24 hours prior to leaching (this was particularly important for $CaCO_3$ amended samples to allow for gas exchange);

- leach cycle length was one hour to minimize secondary sulfide precipitation;

- leachates were filtered (0.45µ) and acidified in 1:10 HNO_3 as soon as possible after collection (samples amended with $CaCO_3$ showed a tendency to form precipitates after collection of leachate if allowed to stand for more than an hour).

- 3 pore volumes of leachate was collected as metal release from most samples was relatively stable after extraction of 3 pore volumes of solution.

Mine Waste Sample

Six mine waste samples were tested as part of the STARS investigation. Results for only one mine waste sample representative of a large extent of streambank tailings is discussed in this report. The tailings sample selected (Table 1) contained an abundance of silt-sized material (45%), with a significant sand content (34%), and a lessor amount of clay (21%). This sample had a pH in a saturation extract of 3.7 and an EC of 7.5 mmhos/cm. Soluble and total metal levels are shown in Table 1.

Table 1. Chemical and physical properties of mine waste sample 537-1-1 collected along Silver Bow Creek near Butte, Montana.

Depth (in)	pH	EC (mmhos/cm)	CEC (meq/100cm)	Sand	Silt	Clay	Saturation (%)
				--------	(%)	--------	
0-15	3.7	7.5	27.0	33.8	45.4	20.8	72.3
			TOTAL METALS (mg/kg)				
Al	As	Cd	Cu	Fe	Mn	Pb	Zn
7320	2560	37.0	3900	38300	4010	2980	7430
			SOLUBLE METALS (mg/kg)				
Al	As	Cd	Cu	Fe	Mn	Pb	Zn
34.0	0.12	4.1	719	1.8	1851	.03	1337

Amendment Materials

A variety of chemical amendments were mixed with the mine waste sample to test their effectiveness in reducing the solubility of metals. Chemical and organic amendments which were tested are listed in Table 2. Amendment application rates, and the primary reaction types expected to reduce metal solubility are also listed in Table 2.

Table 2. Chemical and organic amendments used in column investigation.

Amendment Type	Potential Ameliorating Effect on Tailings	Amendment Material	Rate (in 300g)	Source of Amendment Material
Neutralizing	Acidity Reduction	$CaCO_3$ #1 (Blue)	1.00g	Natures Calcium Products Co., Whitehall, MT
		$Ca(OH)_2$	1.00g	Agribasics Belgrade, MT
		Acetylene waste	1.00g	HRI/Cement Dust NW Spokane, WA
Calcium sources	May reduce uptake of metals by vegetation	$CaCl_2$	0.09g	Dyce Chemical Billings, MT
		Phosphogypsum	1.67g	J.R. Simplot Pocatello, ID
Phosphorus sources	May form insoluble precipitates with metals	Triple super-phosphate	0.33g	Agribasics Belgrade, MT
		Phosphate sludge	0.95g	Stauffer Chemical Butte, MT
Organic Matter sources	Increase metal absorption capacity, plant nutrient source	Manure	7.20g	MSU Nutrition Center Bozeman, MT
		Straw	7.20g	MSU Nutrition Center Bozeman, MT
Other Fixation agents	Increased metal absorption capacity	Zeolite	1.50g	Teague Mineral Products Adrian, OR
		Ferric sulfate	0.69g	Dyce Chemical Billings, MT

[1] - The lime rate was determined using the following formula:

$$LR = [31.25(HNO_3 - S) + 23.44(HCl - S) + SMP][1.25] \qquad [1]$$

where,

LR = Lime requirement (tons/1000 tons waste)
HNO_3-S = Nitric acid extractable sulfur (%)
HCl-S = Hydrochloric acid extractable sulfur (%)
SMP = SMP buffer lime rate (tons/ac)
1.25 = a factor to adjust for field incorporation

Leachate solutions from the columns were analyzed for pH and electrical conductivity (EC) immediately after collection. Selected metals including As, Al, Cu, Cd, Fe, Mn, Pb, and Zn were also analyzed through the EPA Contract Laboratory Program (CLP). Results of Cd, Cu, and As analysis are discussed in this report.

The leachates selected for submission to the CLP included 1) replicated column leachates, 2) a set of treatments with varying mixtures of liming agent, and 3) individual column leachates from unreplicated amendment combinations of interest. Column leachates from key amendment combinations were replicated three times so that differences in soluble metal levels between treatments could be statistically differentiated. A series of samples were submitted to identify the effects of varying the ratio of $CaCO_3$ and $Ca(OH)_2$ as a fraction of the total lime requirement. Finally, a few unreplicated treatments were analyzed to identify the effects of minor changes in the amendment combination.

Sequence of Amendment Combinations Evaluated

Initial tests were aimed at determining the most effective liming material for each waste material. $CaCO_3$, $Ca(OH)_2$, quick lime slurry, acetylene generator waste and combinations of $CaCO_3$ and $Ca(OH)_2$ were the materials tested.

Additional secondary amendments were then tested in conjunction with the most effective liming material. Secondary amendments included manure, straw, triple superphosphate, phosphorous sludge (a phosphate plant waste consisting of material too fine for effective processing), phosphogypsum (the acid-digested waste material from phosphoric acid manufacture), zeolite (clinoptiloite, Ca/Na saturated), calcium chloride, and ferric sulfate.

COLUMN TEST RESULTS

A nearly infinite number of combinations of amendments could have been tested. Hence an approach was needed to reduce the number of amendment combinations. Based upon preliminary testing, it became apparent that lime materials ($CaCO_3$ and $Ca(OH)_2$) were the most effective amendments at reducing metal solubility. As a result, initial column tests focused on identifying the best combination of lime sources. Use of $CaCO_3$ alone did not adequately control pH of the mine waste. $Ca(OH)_2$-amended samples became very basic ($pH > 10$). The pH of these mixtures was expected to gradually drop in response to equilibration with CO_2. Gaseous CO_2 and air was bubbled through the slurry to accelerate the equilibration of samples to a pH consistent with the atmospheric CO_2 concentration (equations 2 - 6). Mixtures of $CaCO_3$ and $Ca(OH)_2$ were expected to provide an effective field lime treatment. The $Ca(OH)_2$ would react quickly to neutralize soil acidity leaving residual $CaCO_3$ for control of remaining acid forming components (sulfides) which may continue to react over time.

$$Ca(OH)_2 = Ca^{2+} + 2OH^- \quad [2]$$

$$CO_2 + H_2O = H_2CO_3 \quad [3]$$

$$H_2CO_3 + OH^- = HCO_3^- + H_2O \quad [4]$$

$$HCO_3^- + OH^- = CO_3^{2-} + H_2O \quad [5]$$

$$CO_3^{2-} + Ca^{2+} = CaCO_3 \quad [6]$$

In order to simplify the interpretation of the column study results, the cumulative metal released throughout each column study was summed. Next the geometric mean pH levels and arithmetic mean EC levels were calculated across all leachate fractions (Table 6.3). Cumulative metal release was expressed on a soil weight basis (mg metal released / kg of soil). The cumulative volume of leachate and the original soil weight were both known. To calculate the cumulative pore volumes of leachate, the following conversion was used. The porosity of the waste can be derived by the following:

Porosity = $1-(d_b/d_p)$
where d_b = bulk density (assumed 1.4 g/cm^3)
d_p = particle density (assumed 2.65 g/cm^3)

Pore volumes = leachate volume / (porosity*(300 g) / d_b

Tailings material tested was very high in metals and in salinity and had moderately low pH levels. $CaCO_3$ was not as effective as either $Ca(OH)_2$ or mixtures of the two in reducing metal levels in leachate (Table 3). It was noted that use of pure $Ca(OH)_2$ caused an undesirable increase in As in leachate and if used in the field might cause high pH (>8.5) conditions for an extended period of time thus delaying seeding. An evaluation of leachate quality with various mixtures of $CaCO_3$ and $Ca(OH)_2$ was performed to identify the optimum combination of liming agents (Figure 2 and 3). Soil pH levels were measured 1 hour after addition of lime but before reacting the system with CO_2 to attain pH equilibrium. Use of $Ca(OH)_2$ to provide 20 to 40 percent of the lime requirement appeared to provide adequate control of Cu and Cd solubility without drastically increasing soluble As levels above those found in the unamended sample.

Several secondary amendments were evaluated in combination with a 60 % $CaCO_3$ / 40 % $Ca(OH)_2$ lime mixture. Use of zeolites or straw increased soluble Cu levels above levels found in the lime treatment by two orders of magnitude. The manure-amended samples did not differ notably from the lime alone. Use of ferric sulfate (a chemical commonly used to remove arsenic from wastewater) in conjunction with lime seemed to reduce levels of soluble As without increasing levels of other metals in leachate. When ferric sulfate is added to soil it dissociates and the free ferric iron hydrolyzes to create iron oxide ($Fe(OH)_3$). Iron oxides are known to have the ability to adsorb soluble arsenate thus reducing soluble As levels. The lime ($Ca(OH_2)$ + $CaCO_3$) / ferric sulfate treatment was selected as the preferred amendment combination.

Table 3. Analysis of leachates from column tests.

SAMPLE NUMBER	TREATMENT	pH	EC (mmhos/ cm)	LEACHATE PORE VOLUMES	Cumulative Metal Released (mg/kg) Al	As	Cd	Cr	Cu	Fe	Mn	Pb	Zn	Ca	Mg
Replicated Treatments															
SET 1[+]	C	4.5 A[*]	8.98 A	2.26 A	22.08 A	.038 A	3.841 A	.002 A	647.14 A	3.854 A	1610.64 A	.095 A	1109.2 A	363 A	339 A
SET 2[+]	CH/CO2	7.4 B	3.18 B	2.45 A	.11 B	.403 A	.004 B	.003 A	.32 B	.043 B	2.93 B	.023 A	.1 B	537 A	110 B
SET 3[+]	CC/CH 60-40/CO2	7.3 B	3.43 B	2.45 A	.32 B	.316 A	.011 B	.001 A	.28 B	.058 B	16.98 C	.009 A	.2 B	506 A	120 B
SET 4[+]	CC/CH 60-40/FS/CO2	6.8 B	3.18 B	2.36 A	.33 B	.039 A	.011 B	.001 A	.19 B	.053 B	19.50 C	.007 A	.2 B	441 A	103 B
Lime Mixtures															
3-19	CC/CH 100-0	6.4	5.24	2.67	.41	.052	.457	.001	.72	.005	825.26	.004	157.0	462	265
3-20	CC/CH 80-20/CO2	6.6	4.05	3.05	.16	.107	.113	.001	.18	.006	438.72	.004	14.2	545	215
3-21	CC/CH 60-40/CO2	6.8	3.29	2.16	.06	.298	.003	.003	.25	.005	10.79	.015	.3	408	93
3-22	CC/CH 40-60/CO2	6.8	3.30	2.65	.16	.453	.003	.003	.29	.005	9.46	.004	.3	524	112
3-23	CC/CH 20-80/CO2	7.0	3.33	2.46	.10	.269	.004	.002	.39	.014	5.94	.007	.3	549	120
3-24	CC/CH 0-100/CO2	7.3	3.22	2.48	.07	.318	.005	.002	.31	.009	4.18	.007	.2	553	121
Single Treatments															
3-02	CC	6.4	6.12	2.42	1.47	.031	.639	.003	5.21	.231	932.56	.041	337.7	347	135
3-14	AW/CO2	5.5	5.43	2.87	.13	.362	.004	.004	.37	.217	5.43	.048	.1	556	81
3-08	CH/Z/CO2	7.8	3.10	3.23	.13	.359	20.008	.001	60.48	.065	8.42	.042	.2	564	133
3-11	CH/S/CO2	7.1	4.37	2.61	.05	.478	10.004	.004	81.57	.020	8.93	.044	.3	239	69
3-10	CH/M/CO2	7.0	3.66	2.76	.05	.349	.004	.002	.52	.019	7.62	.046	.1	224	58

[*] Numbers within a column followed by the same letter are not significantly different at p=.05, all numbers are geometric means of three values.

[+] set 1 = tempe cell runs 3-01, 3-06, 3-07
set 2 = tempe cell runs 3-17, 3-18, 3-24
set 3 = tempe cell runs 3-26, 3-27, 3-21
set 4 = tempe cell runs 3-25, 3-29, 3-30

Treatments

C - control (no amendments)
CC - Calcium carbonate
CH - Calcium hydroxide
CO2- CO2 treated
PG - Phosphogypsum
PR - Phosphate rock
FA - Flyash
Z - Zeolites
40/60 - percentage of CaCO3 and Ca(OH)2 added
FS - Ferric sulfate
M - Manure
S - Straw
AW - Acetylene Waste
PS - Phosphate sludge

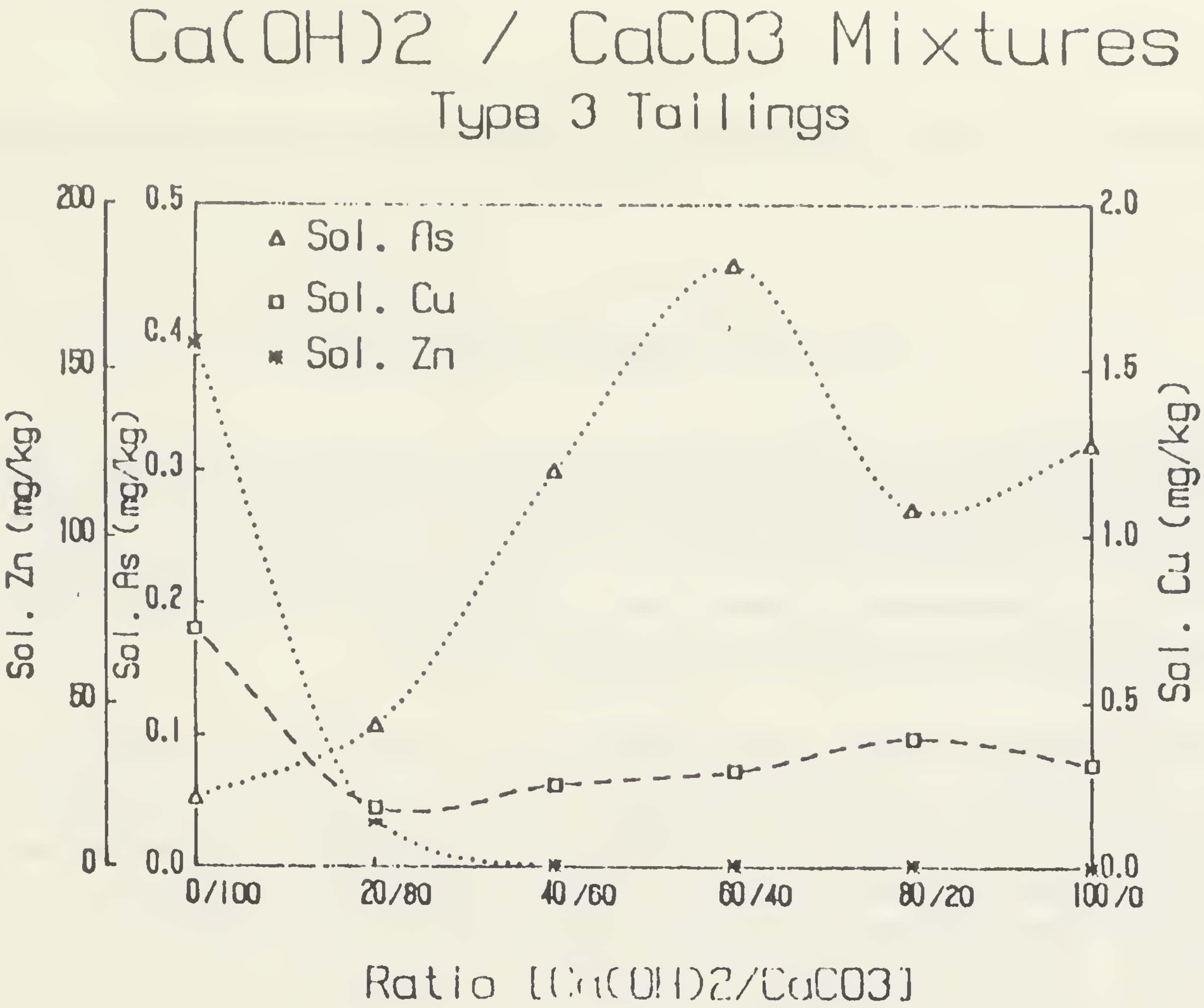


Figure 2 Effect of various mixtures of $CaCO_3$ and $Ca(OH)_2$ on the release of Cu, Zn and As from class 3 wastes.

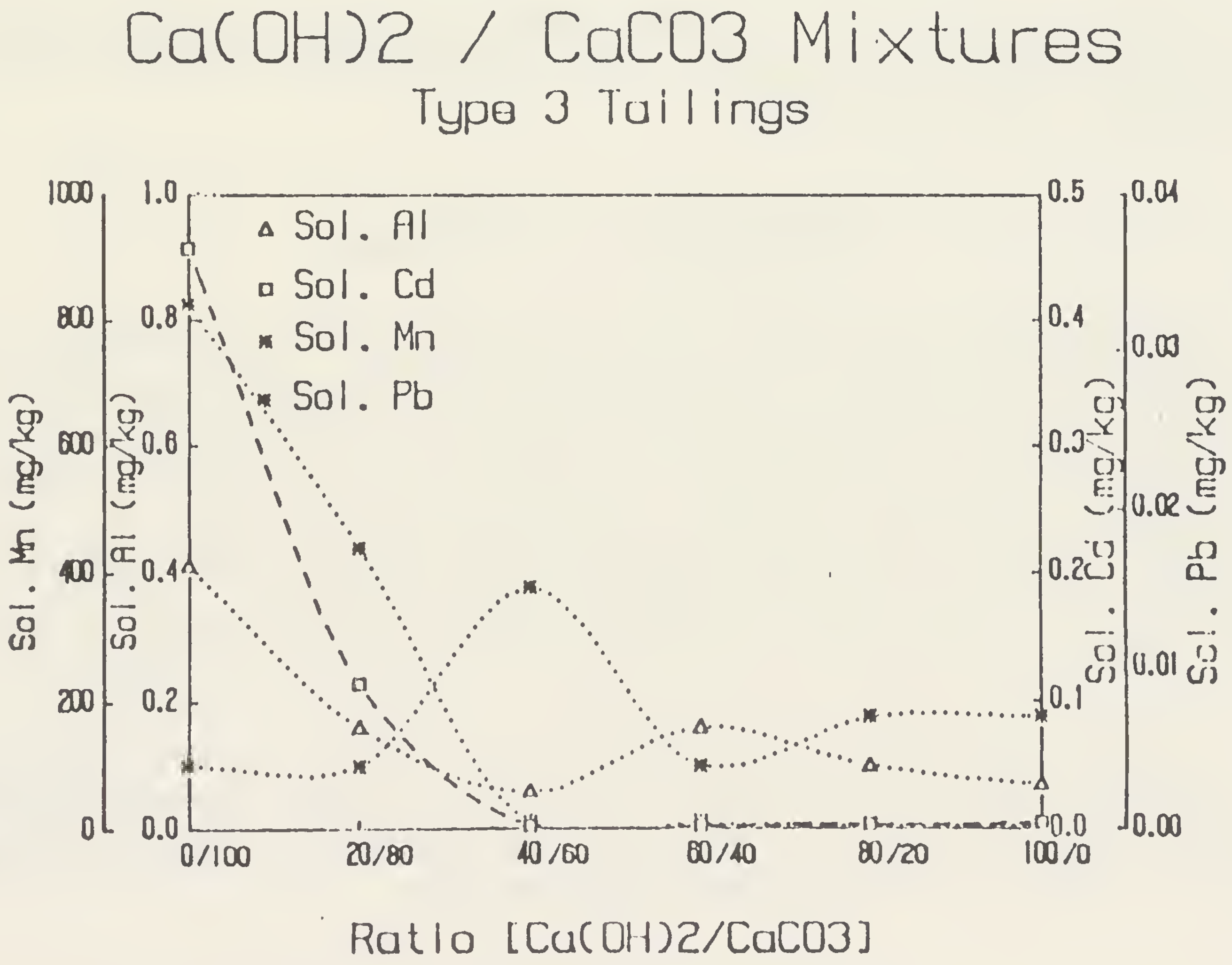


Figure 3 Effect of various mixtures of $CaCO_3$ and $Ca(OH)_2$ on the release of Pb, Cd, and Mn from class 3 wastes.

GEOCHEMICAL INTERPRETATION OF COLUMN RESULTS

Soil Geochemistry Background

Soil geochemistry uses thermodynamic data to interpret the partitioning of metals in various solid and solution phases in soils and sediments. Thermodynamic data is based on the solubilities and reactions of pure solids in water and caution must therefore be exercised in the interpretation of these data as they apply to a non-equilibrium system, such as is represented by the streambank tailings material.

In such a system, several mechanisms may be active which can significantly affect the interpretation of the thermodynamic data. Solids may be poorly crystallized and thus may not fit thermodynamic data for crystallized material. Mixed solid-solution series, such as jarosite-alunite may be active in the system. Isomorphic substitution of cations of different valence states (Mn^{2+} for Fe^{3+}) can change the electrochemical equilibrium of the soil solid spaces. Adsorption reactions, both specific (arsenates on iron hydroxides) and nonspecific (cations on clays) as well as co-precipitation of cations must also be considered. In addition, defining the ion-pairs which are present in solution and their concentration can prove to be difficult.

However, the use of thermodynamic data and solubility diagrams in conjunction with laboratory leachate data provides a useful and convenient method for the analysis and discussion of laboratory results.

Thermodynamic Calculations

Thermodynamic data derived from controlled laboratory experiments can be used to construct solubility diagrams. These diagrams show changes in the solubility of several solid phase minerals with varying ion activity and pH. To examine the effects of changing pH on the concentration of metals in solution, it was necessary to assume fixed concentration for several other species. Values for ion activity used for the construction of solubility diagrams in this study included: $[SO_4^{-2}]=10^{-2.0}$, $[F^-]=10^{-6.0}$, $[CO_2]=10^{-2.5}$ and $[H_2SiO4^\circ]=10^{-2.66}$. These values were chosen based on chemical analysis, EC levels and review of pertinent scientific literature (Lindsay 1979, Stumm and Morgan 1981).

In Phase I of STARS, the total dissolved concentration of several metals in tempe cell extraction leachates was recorded. In order to construct solubility diagrams, ion concentration data needed to be converted to ion activity data. This was accomplished through the employment of an activity coefficient where:

$$A = \delta_i C$$

where

A = activity
δ_i = ion activity coefficient
C = ion concentration

The extended Debye-Huckel equation (Lindsay 1979) was used to calculate the ion activity coefficient. This equation is based on electrostatics and thermodynamics and assumes that ions behave like point charges in a continuous medium with a dielectric constant equal to that of the solvent where:

$$\log\delta_i = -AZ_i^2 \frac{(\mu^{1/2})}{(1 + Bd_i\mu^{1/2})}$$

and

A = 0.509 for water at 25°C
B = 0.328×10^8 for water at 25°C
Z = valence
d_i = effective size of hydrated radius of ion
μ = ionic strength = 13(EC mmhos/cm)

Table 4 shows the valence and ionic radii values used in the calculation of the extended Debye-Huckel activity coefficients for the ions of concern.

Table 4 Valence and ionic radius of leachate ions.

Ion	Valence	Ionic Radius cm x 10^{-8}
H^2AsO4	-1	4.5
Cd	+2	5.0
Cu	+2	6.0

Ion-pairing Thermodynamic Data

Leachates were analyzed for total aqueous metals in solution. This value is the sum of various metal species in solution. For example, copper may be present as both dissociated Cu^{+2} and ion-paired $CuSO_4^{o}$. Because most thermodynamic data are usually presented as the activity of the free ion (ie:Cu^{+2}) in solution, it was necessary to calculate a distribution coefficient to equate total aqueous ion (Cu_{aq}) to free aqueous ion (Cu^{+2}), for which data are available. The distribution coefficient was calculated in the following manner:

$$\alpha_{Cu} = \log (Cu^{+2}/Cu_{aq})$$

where α_{Cu} varies with pH.

An example of how this coefficient is employed is shown below for copper:

$$\log (Cu^{+2}) = 13.62 - 2pH$$

Thus

$$\log (Cu_{aq}) = \log (Cu^{+2}) - \alpha_{Cu} = 13.62 - 2pH - \alpha_{Cu}$$

The calculation and employment of a distribution coefficient and the use of the extended Debye-Huckel activity coefficient enabled the construction of solubility diagrams and aqueous phase diagrams for each metal analyzed in the leachate data.

Construction of Solubility and Aqueous Phase Diagrams

The solubility diagrams for the column leachate samples consisted of a plot of soluble metal against pH. The equilibrium solution concentration for several solid species which may be governing metal solubility are shown as lines on the solubility diagrams. Data points which are above the line for a solid species suggest the solution is "oversaturated" with respect to that mineral under ideal conditions, his mineral would precipitate in such a solution. Data points below the line suggest the solution is undersaturated, meaning that solid species is probably not present in this sample.

Published thermodynamic data (Hess and Blanchar 1976, Lindsay 1979, Stumm and Morgan 1981) were used to construct aqueous species diagrams. These diagrams indicate the activity of several aqueous species in solution against pH. The solids assumed to be controlling ion solubility are indicated at the top of each diagram. Table 5 summarizes, by ion, the solid phases presumed to control solubility, primary aqueous species present and the equations used to construct the solubility diagrams.

Table 5 Solid phase minerals which may control ion solubility in Silver Bow Creek mine waste samples and typical aqueous species at various pH levels.

ION	SOLID PHASE CONTROLLING SOLUBILITY	FORMULA	AQUEOUS SPECIES	
Al	gibbsite,($Al(OH)_3$) pH<5	$8.13-3pH-\alpha Al^{+3}$	$AlSO_4^{\circ},AlF^{+2},AlF_2^{+}$	pH<5.5
	amorphous $Al(OH)_3$ pH>5	$9.66-3pH-\alpha Al^{+3}$	$Al(OH)_3^{\circ},Al(OH)_2^{+}$	pH 5.5 to 8
			$Al(OH)_4^{-}$	pH>8
As	$FeAsO_4 \cdot 2H_2O$	$-13.67+pH-\alpha H_2AsO_4$	metal arsenates	pH<4.5
	adsorption	$-13+pH-\alpha H_2AsO_4$(pH6 to 8)	$H_2AsO_4^{-}$	pH 3-6.7
			$HASO_4^{-2}$	pH 6.7-11
Cd	adsorption	$1-2pH-\alpha Cd^{+2}$(pH <7.5)	$Cd^{+2},CdSO_4^{\circ}$	pH<7.8
	octavite ($CdCO_3$)	$8.66-2pH-\alpha Cd^{+2}$(pH >7.5)	$CdCO_3^{\circ},CdHCO_3^{+}$	pH>7.8
Cu	bronchantite ($Cu_4(OH)_6SO_4$)	$4.34-1.5pH-\alpha Cu^{+2}$	$CuSO_4^{\circ},Cu^{+2}$	pH<6
	malachite ($Cu_2(OH)_2CO_3$)	$7.75-2pH-\alpha Cu^{+2}$	$Cu(CO_3)_2^{-2},CuCO_3^{\circ}$	pH>6
	adsorption	$1-pH-\alpha Cu^{+2}$		
Fe	amorphous ($Fe(OH)_3$)	$3.54-3pH-\alpha Fe^{+3}$	$Fe^{+2},FeSO_4^{\circ},Fe(OH)^{+2},Fe(SO_4)_2^{-}$	pH<4
	jarosite ($KFe_3(SO_4)_2(OH)_6$)	$-1.5-2pH-\alpha Fe^{+3}$	$Fe(OH)_2^{+},Fe(OH)_3^{\circ}$	pH 4-8
			$Fe(OH)_4^{-}$	pH>8
Mn	magnesite ($MnOOH$)	$9.27-2pH-\alpha Mn^{+2}$	$Mn^{+2},MnHCO_3^{+}$	pH 3-9
Pb	anglesite ($PbSO_4$)	$-5.79-\alpha Pb^{+2}$	$PbSO_4^{\circ},Pb^{+2},Pb(SO_4)_2^{-2}$	pH<6.5
	cerussite ($PbCO_3$)	$7.15-2pH-\alpha Pb^{+2}$	same, $Pb(OH)^{+}$	pH>6.5
	adsorption	$-2-pH-\alpha Pb^{+2}$		
Zn	Franklinite ($ZnFe_2O_4$)	$4.45-2pH-\alpha Zn^{+2}$	$ZnSO_4^{\circ},Zn^{+2}$	pH<8
	$Zn(OH)_2 \cdot ZnSO_4$	$4.25-pH-\alpha Zn^{+2}$	$Zn(OH)^{+}$	pH>8
	smithsonite ($ZnCO_3$)	$10.41-2pH-\alpha Zn^{+2}$		

Arsenic Geochemistry

The control samples are much higher in As_{aq} than would be anticipated if iron and aluminum arsenates were controlling arsenic solubility, unless unknown ion-pairs are controlling the total As_{aq} at low pH rather than $H_2AsO_4^{\circ}$ and $H_3AsO_4^-$ activities. The formation of $Pb_3AsO_4 \cdot 4H_2O$ does not appear to control As_{aq} at low pH. The lime-amended samples seem to follow the $FeAsO_4.2H_2O$ and $AlAsO_4.2H_2O$ solubility lines in the pH range 6.0 to 8.0 (Figure 5), possibly due to specific adsorption of $H_2AsO_4^-$ by iron oxides. This phenomenon is illustrated below in Figure 4 for $H_2PO_4^-$, which behaves very much like $H_2AsO_4^-$ in the soil (Bohn et al 1985).

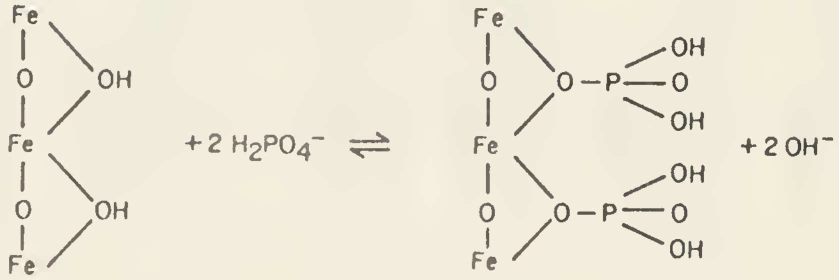


Figure 4 Specific adsorption of $H_2PO_4^-$ by iron oxide.

The aqueous species of arsenic in equilibrium with $FeAsO_4.2H_2O$ are $H_3AsO_4^{\circ}$ at a pH value less than 2.0 and $H_2AsO_4^-$ between pH values 2.0 and 6.7 (Figure 6). Above a pH of 6.7, $HAsO_4^{-2}$ is dominant. At pH values less than 5.0 unknown metal-arsenate, ion-pairs may constitute a significant portion of As_{aq}. No data were available on the stability of metal - arsenate ion pairs

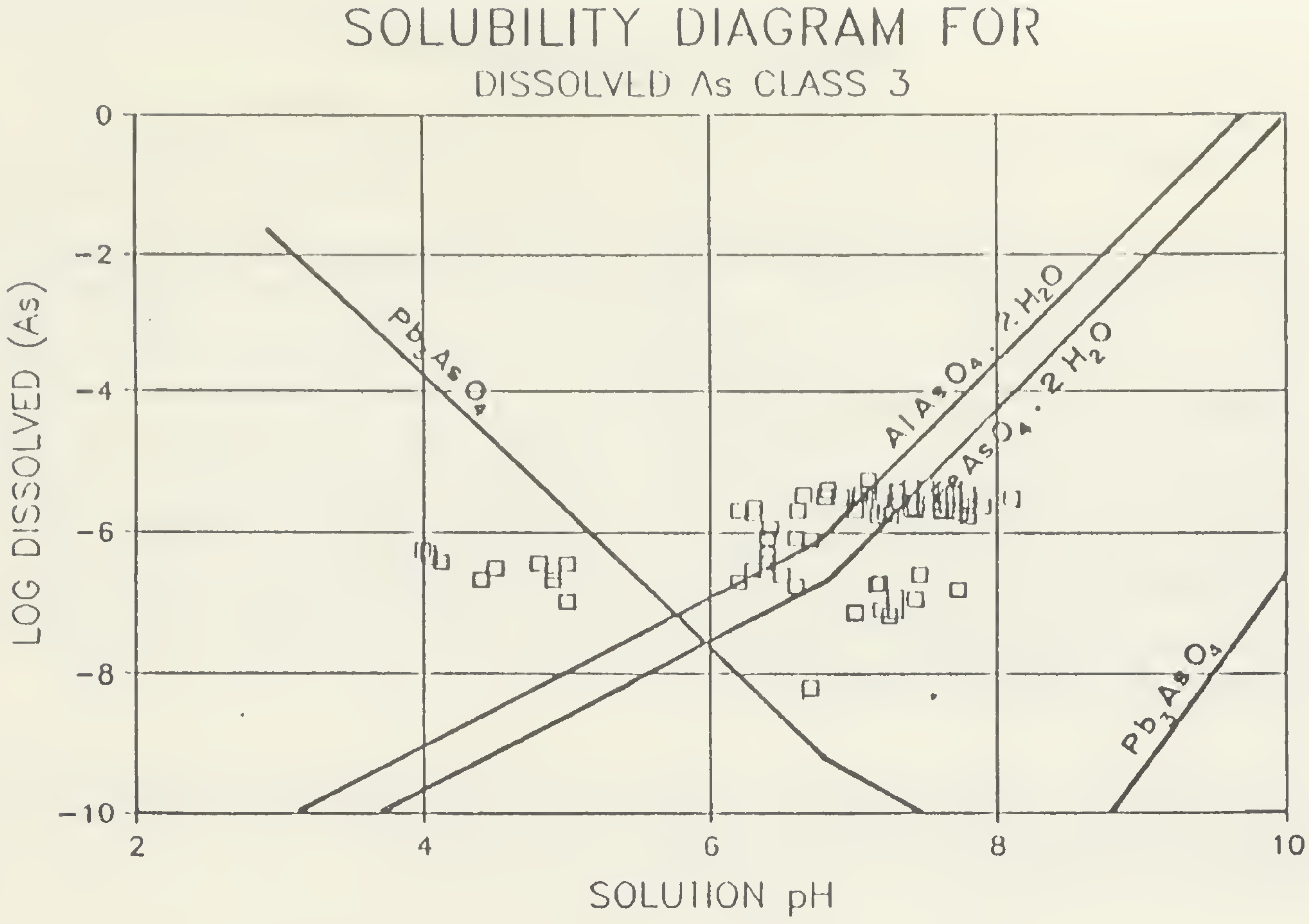


Figure 5. Solubility diagram for As_{aq} in mine waste leachates. Lines indicate the hypothetical levels of As_{aq} for systems in equilibrium with various arsenic minerals.

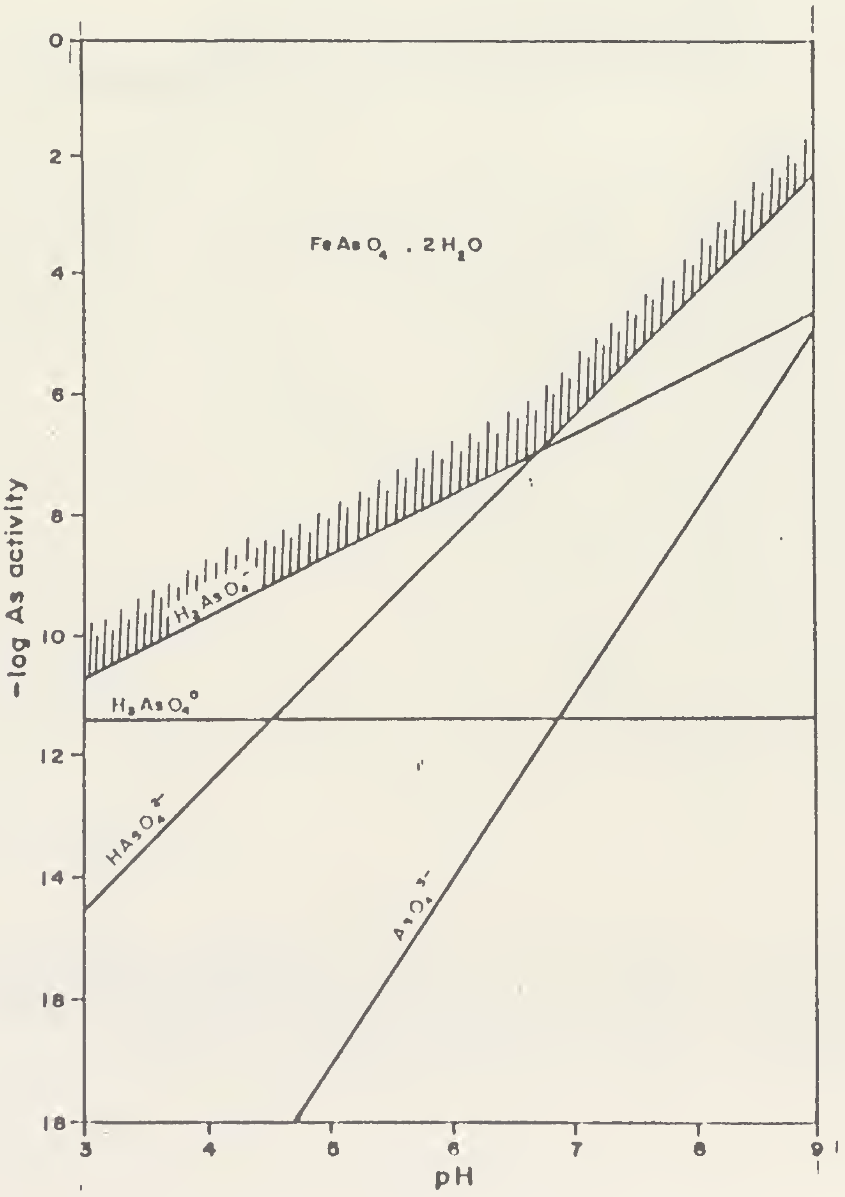


Figure 6. Aqueous As species in equilibrium with $FeASO_4.2H_2O$ (where $CO_2=10^{2.5}$).

Cadmium Geochemistry

The amount of Cd_{aq} does not appear to be significantly controlled by any solid phase, except at pH values greater than 7.5., where cadmium solubility may be controlled by $CdSiO_3$ or octavite (Figure 7). Below this pH level, Cd_{aq} is most likely controlled by adsorption. The reason for Cd_{aq} values plotting slightly above the soil cadmium line may be due to the existence of an abundance of $CdSO_4^{o}$ aqueous ion pairs. The soil Cd line was obtained from thermodynamic data reported by Lindsay (1979) and represents the average Cd values found over a wide range for various soils. It is evident that cadmium sulfates are not controlling Cd_{aq} levels. several amended samples with a pH above 7.0 appear to follow the solubility line for octavite or $CdSiO_3$ (Figure 7). The group of points showing elevated Cd_{aq} levels at pH 6.0 to 7.0 and (Cd)=10^{-5} to 10^{-7} depicts calcium carbonate-amended tailings and indicates that this is not an effective amendment for reducing levels of cadmium in solution.

The dominant aqueous species of cadmium present up to a value of pH 7.8 are Cd^{+2} and $CdSO_4^{o}$ (Figure 8). Above this pH value and coincident with the octavite stability field, $CdHCO_3^{+}$ and $CdCO_3^{o}$ become most prevalent.

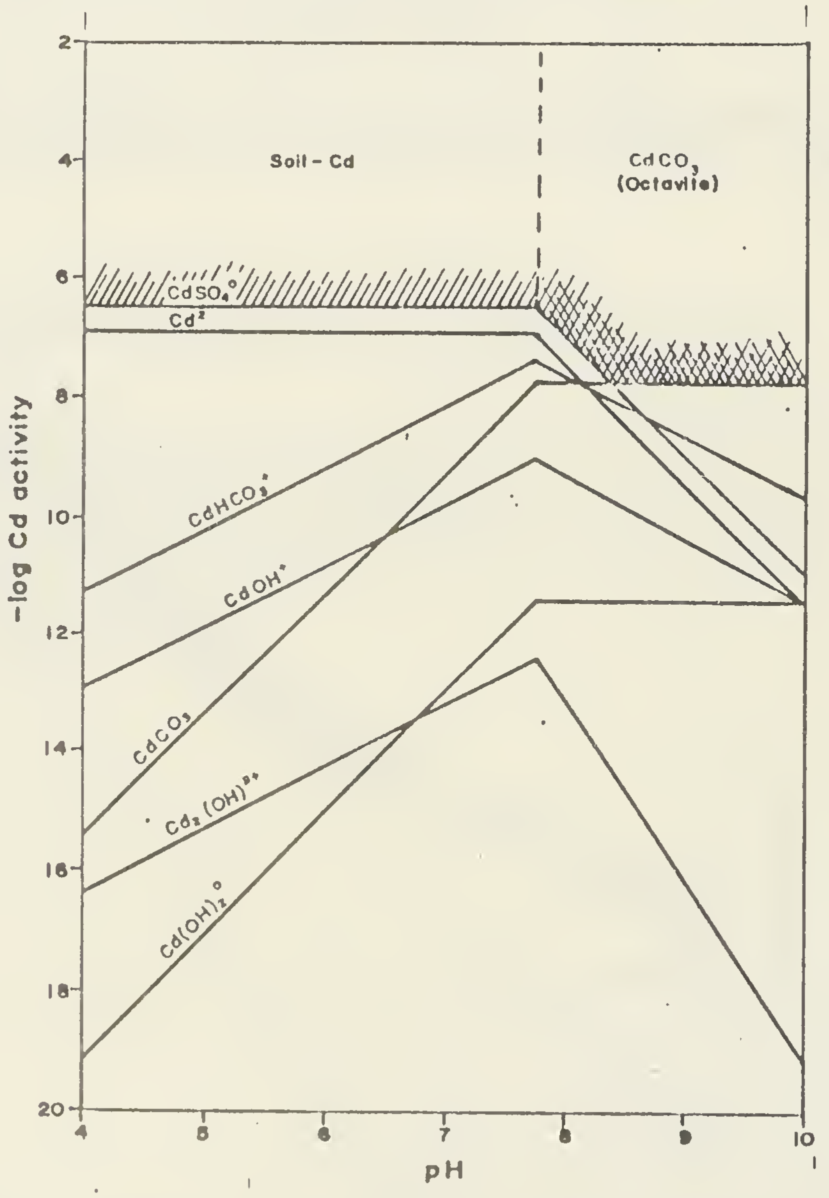


Figure 7. Solubility diagram for Cd_{aq} for all tailings classes in the STARS Phase I Investigation. Lines indicate the hypothetical levels of Cd_{aq} for systems in equilibrium with various cadmium minerals.

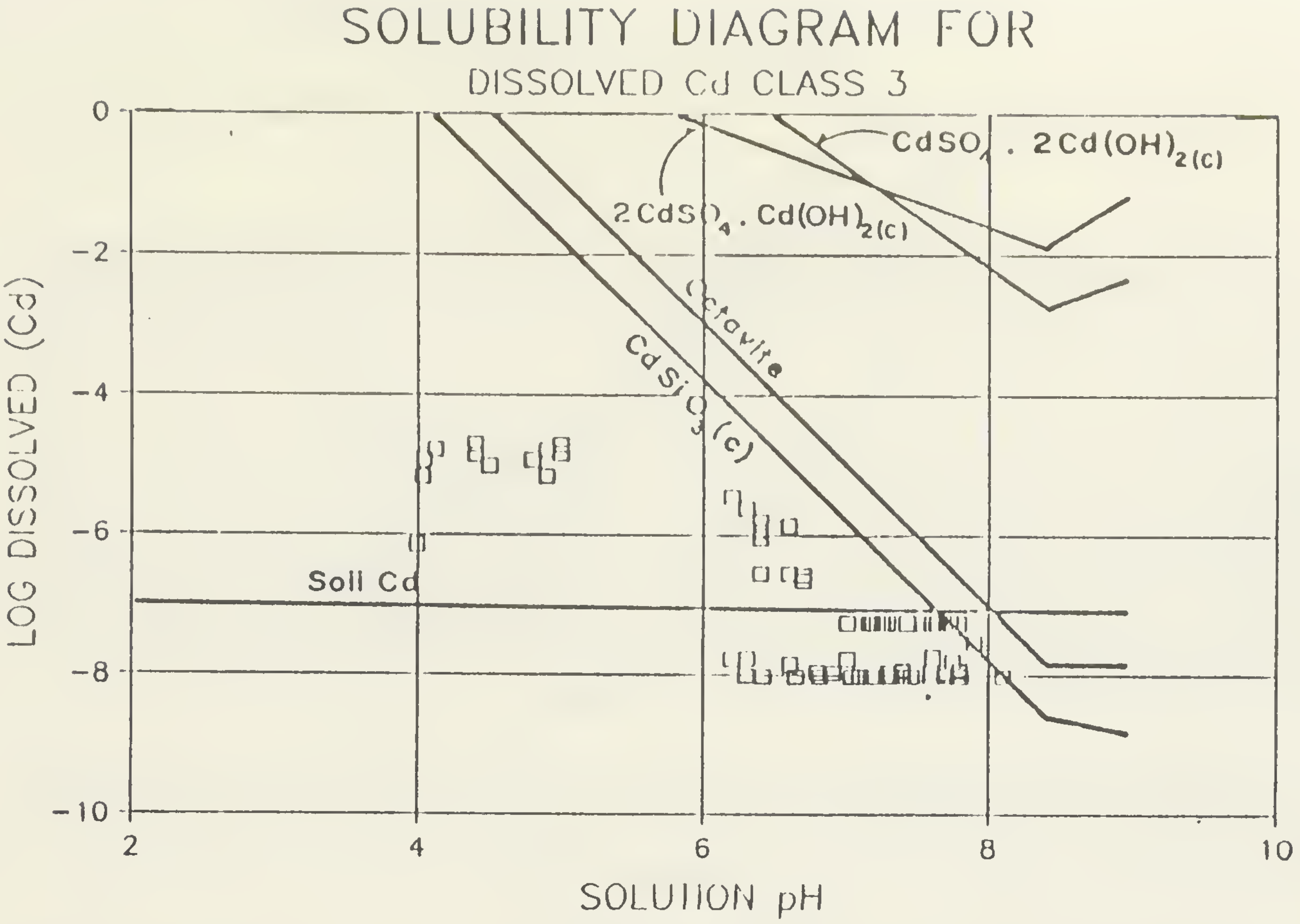


Figure 8. Aqueous Cd species in equilibrium with soil-cadmium and octavite (where $CO_2=10^{-2.5}$, $SO_4^{-2}=10^{-2}$ and $CaCO_{3(s)}$).

Copper Geochemistry

Waste material tested exhibits much higher Cu_{aq} values than traditionally observed in soil systems (Lindsay, 1978). Soluble copper levels in the control samples are coincident with the cupric ferrite stability line and are slightly undersaturated but parallel to the bronchantite stability line. The amended samples, in the pH range 6.0 to 8.0, become oversaturated with respect to cupric ferrite (Figure 9), possibly due in part to the significant decrease in free iron with increasing pH. Malachite or tenorite appear to control the upper threshold of copper solubility in this pH range, and adsorption by metal oxides and clays may also play a role. The lime-amended samples showing the least reduction in copper solubility (pH 6.0 to 7.5 and $(Cu)=10^{-3.5}$ to 10^{-5}) are those amended with calcium carbonate. Addition of $CaCO_3$ as a liming source may cause $CuCO_3$ coatings to form on $CaCO_3$ particles thus maintaining elevated Cu_{aq} levels. Similarly, addition of organic amendments appear to result in higher soluble Cu_{aq} levels. This may have been caused by increased levels of soluble organic ligands (fulvic acids) which chelated free Cu^{++} thus increasing total aqueous Cu.

At pH values less than approximately 6.0, $CuSO_4^{\circ}$ and Cu^{+2} are the most prevalent forms of Cu_{aq}. Above this value and coincident with the malachite stability region, $CuCO_3^{\frac{1}{2}}$ and $Cu(CO_3)_2^{-2}$ become the dominant species of copper in solution (Figure 10).

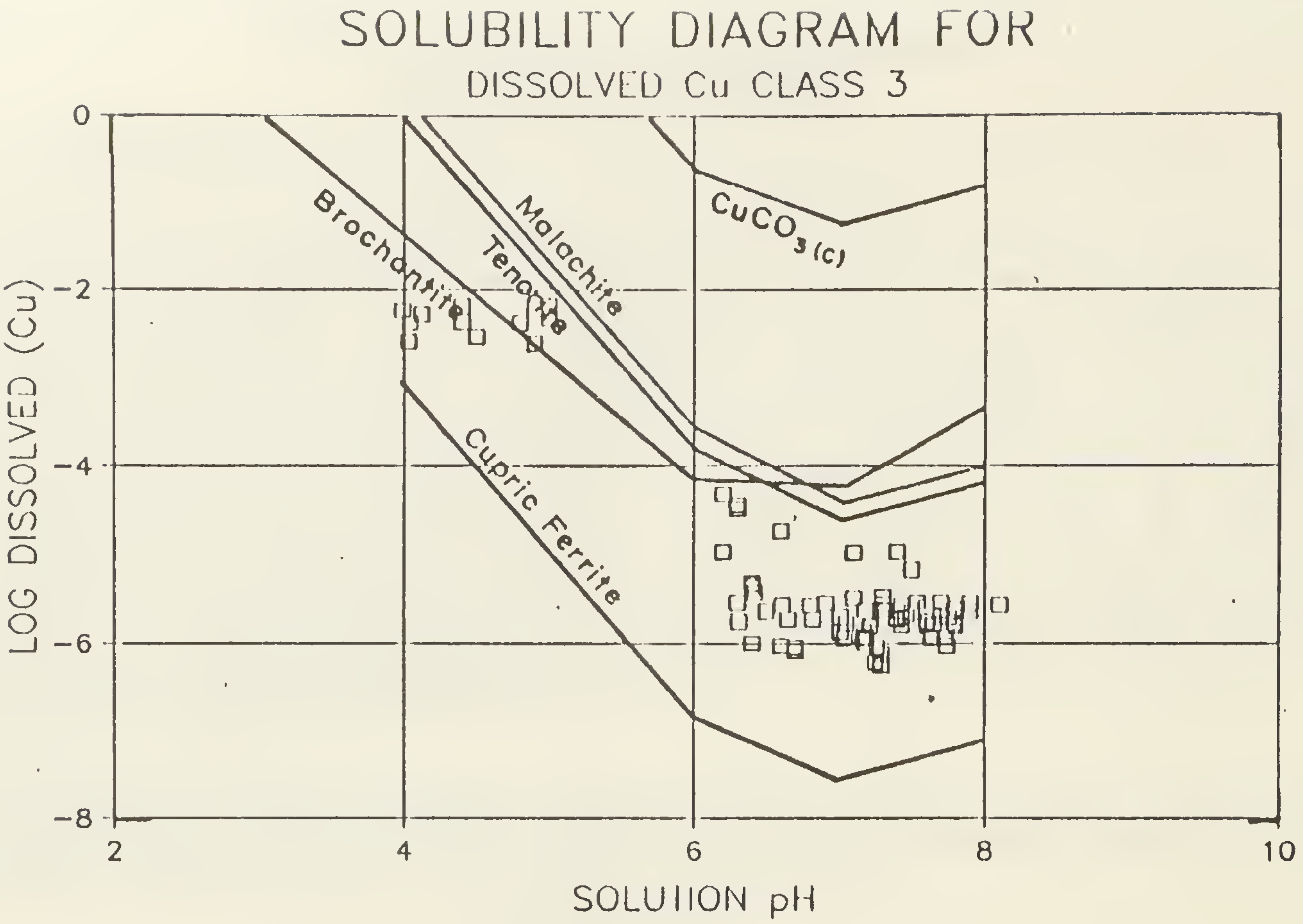


Figure 9. Solubility diagram for Cu_{aq} in mine waste leachates. Lines indicate the hypothetical levels of Cu_{aq} for systems in equilibrium with various copper minerals.

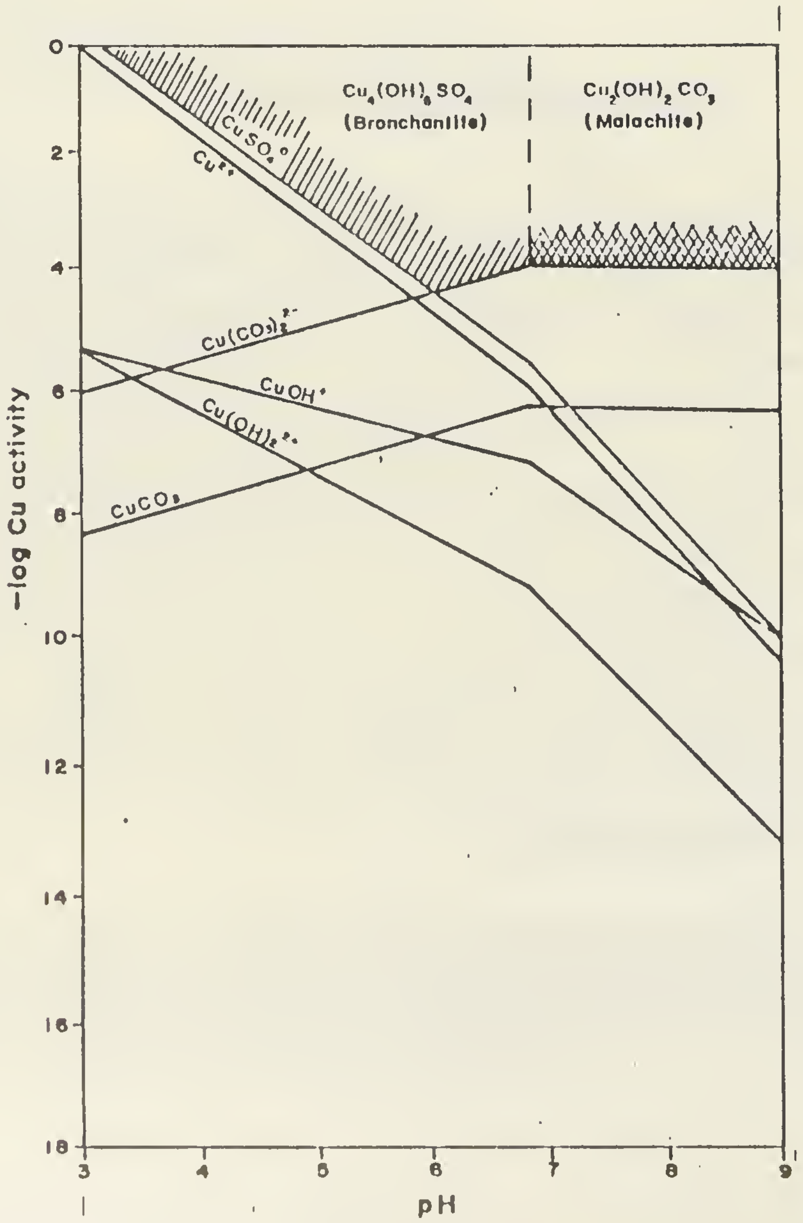
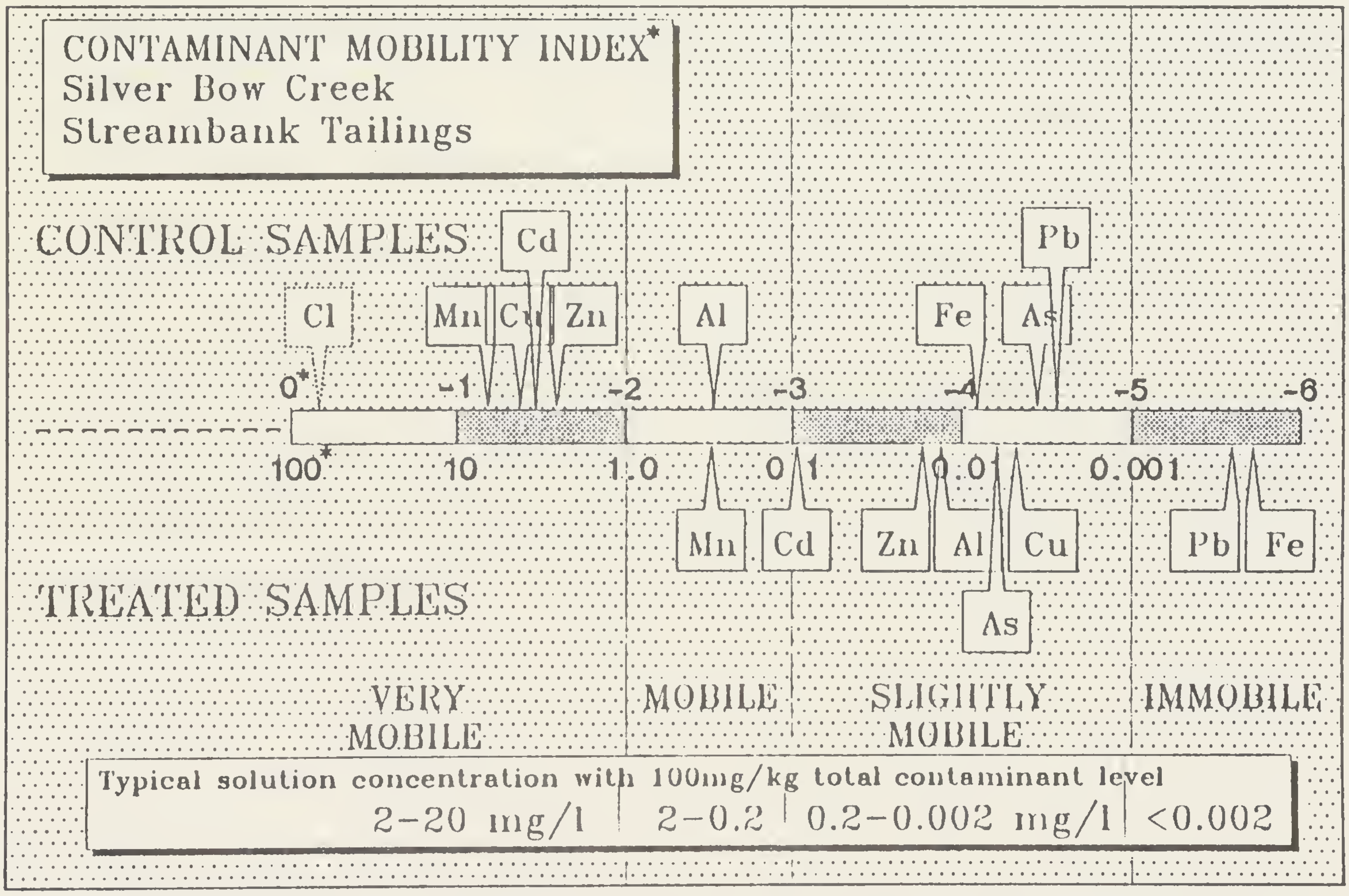


Figure 10. Aqueous Cu species in equilibrium with bronchantite and malachite (where $CO_2=10^{-2.5}$, $SO_4^{-2}=10^{-2}$ and $CaCO_{3(s)}$).

SUMMARY AND RECOMMENDATIONS

Overall, chemical amendments were effective in reducing solubility of metals but had little effect on potential As mobility. Figure 11 illustrates the fraction of each total element leached by 1 pore volume of water. Points shown are the geometric means of six waste materials tested for the unamended (top) and a selected amendment combination (bottom). A hypothetical value for potential chloride mobility is shown for comparison.

The combination of liming agents which appeared to best reduce the levels of Cu, Zn, and Mn without causing substantial release of As, was to use $Ca(OH)_2$ to supply 20 to 40% of the total lime rate. In the treated samples, only Mn remained fairly soluble while Cd, Zn, Al, and Cu were only slightly soluble (.1 to .001% leached in 1 pore volume). Finally, Pb and Fe were insoluble (<.001% released) upon treatment.



* – The "Mobility Index" is defined as the quantity of contaminant leached in 1.0 pore volume divided by the total concentration. Log units are shown on the upper scale while percent is shown on the bottom scale.

Figure 11. The relative mobility of untreated and treated mine waste samples is depicted. The solubility of most metals was substantially reduced.

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GEOCHEMISTRY OF ARSENIC-BEARING GOLD MILL TAILINGS IN THE CHEYENNE RIVER SYSTEM, SOUTH DAKOTA

Walter H. Ficklin

ABSTRACT

Alluvial flood-plain sediments in the Cheyenne River System, South Dakota, contain arsenic and trace metals derived from about 100-million metric tons of gold mill tailings that were discharged into Whitewood Creek between 1876 and 1977. Research activities of the U.S. Geological Survey and other studies indicate that widespread contamination by arsenic occurs along Whitewood Creek, the Belle Fourche River, the Cheyenne River, and in the sediments of the Cheyenne River arm of Lake Oahe. The level of contamination is stable, but it will continue for a long period of time. Some of the tailings may be remined to extract gold that was not recovered in the first ore processing. The reworked tailings should be disposed of in a manner to lessen the extent of arsenic contamination.

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INTRODUCTION

Waste materials from mining and ore processing and their effect on the environment present a special challenge to mine operators. Many of these wastes contain toxic heavy metals and the legendary poison, arsenic. The waste is generated in enormous volumes when a large mine or several mines operate for many years. A common practice for the disposition of mill tailings was to deposit them in a nearby stream. Thus many streams are contaminated with heavy metals and arsenic. Examples of such contamination are the Clark Fork River in Montana, the South Fork of the Coeur d'Alene River in Idaho, and the Whitewood Creek-Belle Fourche River-Cheyenne River system in South Dakota.

Gold mining has been in progress at Deadwood and Lead, South Dakota, since the first discovery of gold there in 1875. Mill tailings were discarded in Whitewood Creek until the late 1970's (Goddard, 1987). Whitewood Creek flows into the Belle Fourche River, which in turn flows into the Cheyenne River (fig. 1). The tailings contain arsenopyrite (FeAsS), an arsenic-bearing sulfide mineral that is associated with the gold deposits at the Homestake mine in Lead, South Dakota (Noble, 1950). Goddard and Wuolo (1987) reported that about 100 million metric tons of finely ground, arsenic-bearing metallic sulfides were discharged into Whitewood Creek at Lead and Deadwood since 1875. The tailings have been distributed along the length of Whitewood Creek and several kilometers farther along the Belle Fourche River. This introduction of fine-grained material has changed the stream morphology, resulting in extensive overbank deposits of unoxidized tailings. Some meanders have been completely filled with tailings (Fuller and others, 1987).

According to Goddard (1987):

> To comply with environmental laws enacted in the early 1970's, including the U.S. Environmental Protection Agency's Ore Mining and Dressing Effluent Guidelines, the current mining operator implemented the Grizzly Gulch Tailings Disposal Project. A 70-m- (meter) high earth and rockfill dam was constructed across a steep, narrow canyon (Grizzly Gulch), about 5 km (kilometers) south of the mine and mill area to create an impoundment area for tailings storage. The tailing disposal system became operational on December 1, 1977, and no discharge of tailings has occurred since that time.

The cessation of tailings discharge has stopped additional contamination of Whitewood Creek. However, the tailings from the many years of discharge remain as an almost inexhaustible source for potential arsenic contamination on the flood plains of Whitewood Creek and the Belle Fourche River.

Whitewood Creek originates in the Black Hills as ground-water discharge in a limestone formation. At Lead and Deadwood, it flows through metamorphic and intrusive rocks. Below Lead, it flows through shale and limestone and enters the Great Plains. The Belle Fourche and Cheyenne Rivers originate in Wyoming and flow mainly through shale (Goddard, 1987). Whitewood Creek is a small stream with an annual discharge of about 1.4 cubic meters per second at its mouth. The Belle Fourche and Cheyenne Rivers have a discharge of about 10 cubic meters per second.

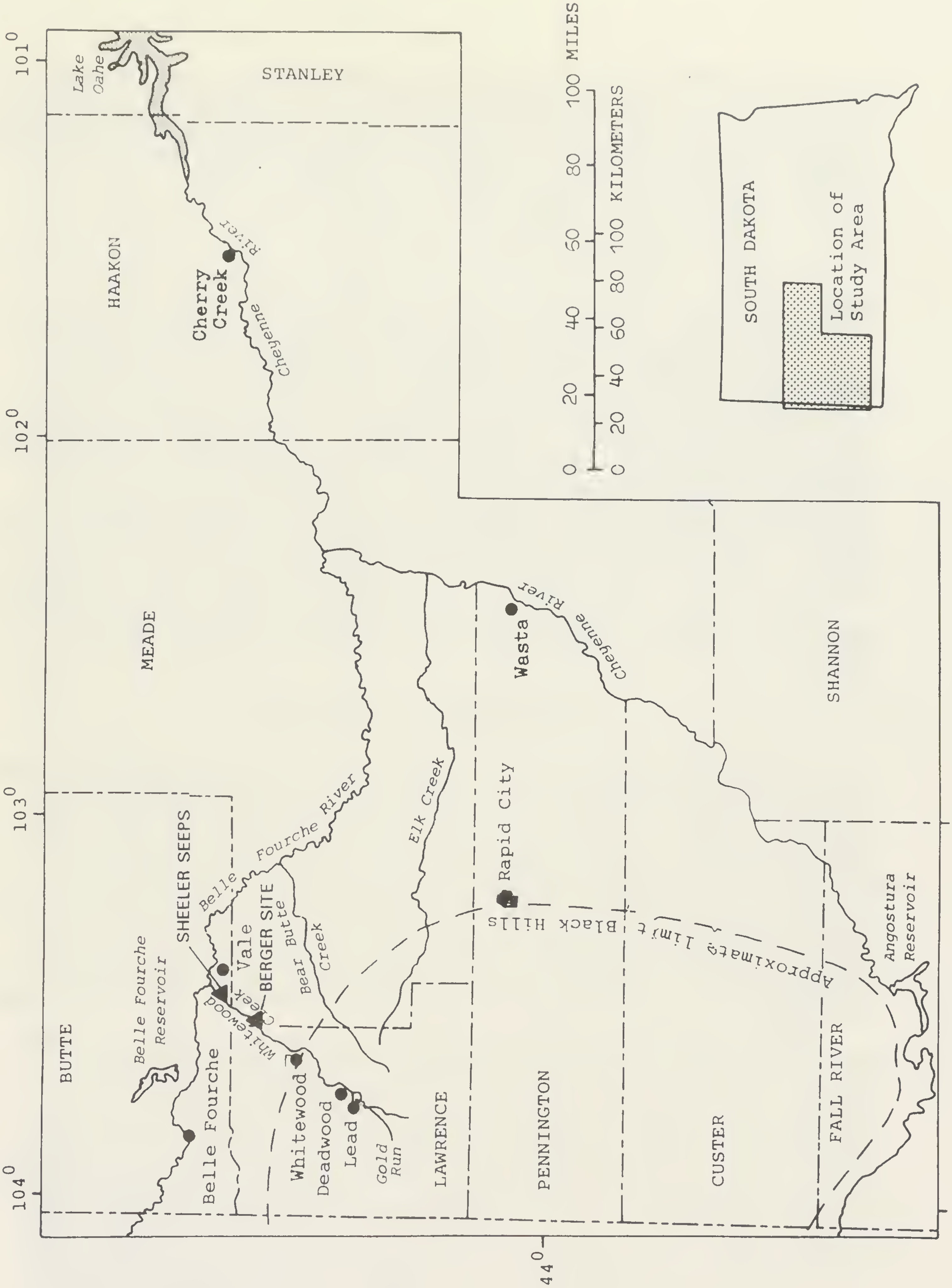

Figure 1.--Location of Whitewood Creek, Belle Fourche River-Cheyenne River, and Lake Oahe, South Dakota.

As a general rule sulfide minerals are chemically very stable in their native locations, but, once exposed to the weathering environment, the action of water and oxygen tends to break them down into more mobile and soluble phases. The oxidation of pyrite has been studied in detail (Stumm and Morgan, 1981). The reaction sequences follow:

1. $FeS_2 + 7/2\ O_2 + H_2O = Fe^{++} + 2\ SO_4^{=} + {}_2H^{+}$
2. $Fe^{++} + 1/4O_2 + H^{+} = Fe^{+++} + 1/2H_2O$
3. $Fe^{+++} + 3H_2O = Fe(OH)_3 + 3H^{+}$
4. $FeS_2 + 14\ Fe^{++} + 8H_2O = 15Fe^{++}\ 2SO_4^{=} + 16H+$

The oxidation of 1 mole of pyrite yields 4 moles of H+, which produces one of the most acidic of all weathering reactions and results in "acid-mine drainage" all over the world. Arsenopyrite is oxidized somewhat analogously to release arsenic as arsenate (As(V), the most oxidized form of arsenic) with arsenite (As(III), the more toxic form) as an intermediate product (Ehrlich, 1964). The process is catalyzed by thiobacillus-ferrobacillus bacteria. The tailings released into the environment along Whitewood Creek have undergone similar reactions, which have released some of the arsenic from its sulfide mineral. The arsenic has entered the stream water, it has been reported in the ground water of the flood plain, and it certainly has been moved in the sediment of the stream system. The characterization of the dispersion of the tailings and the pathway for arsenic mobilization have been the focus of a concerted effort by the U.S Geological Survey since April 1985.

GEOCHEMISTRY OF THE ARSENIC

Visible evidence of the tailings can be found along Whitewood Creek and the Belle Fourche River. At several locations the banks of the stream are made up of layers of red oxidized tailings and black-gray reduced tailings. A sample of the oxidized tailings contained 3,500 milligrams per kilogram (mg/kg) of arsenic, of which 3,000 mg was arsenate, whereas another sample of the reduced tailing contained 4,000 mg/kg of arsenic, mostly bound as arsenopyrite (W.H. Ficklin, unpublished data). Goddard (1987) reported that 95 samples collected from contaminated sediment in the Whitewood Creek area had a mean concentration of 1,920 mg/kg and a maximum concentration of 11,000 mg/kg of arsenic.

Arsenate and arsenite are adsorbed by "reactive iron", i.e. iron that is not part of the silicate structure of the minerals in the sediment (Fuller and others, 1987; Pierce and Moore, 1982). Reactive iron is made up mostly of iron oxyhydroxides. According to equation three above, a large component of reactive iron occurs in the sediments oxidizing pyrite and arsenopyrite of the Whitewood Creek-Belle Fourche River system. Arsenic is transported in the sediment as arsenite and arsenate adsorbed on the iron oxyhydroxides, and, quite likely, the sediment also contains some of the original tailings. Horowitz and Elrick (1987) found arsenopyrite, octahedral pyrite, and detectable concentrations of arsenic associated with iron and manganese oxide coatings in the suspended sediment of the Cheyenne River at Cherry Creek in 1985, about 16 kilometers (km) from the mouth of the Cheyenne River but nearly 200 km from the source of the arsenic. Erosion during high runoff would probably increase the amount of unoxidized tailings transport. With the weathering processes continuing, arsenic is constantly dispersed. Arsenic concentration in the bottom sediments of Whitewood Creek in August 1985 reached slightly more than 1,000 mg/kg downstream of Lead. Upstream of Lead the concentration was 15 mg/kg (Goddard and others, 1987). In the Belle Fourche River, the arsenic was more concentrated near the mouth of Whitewood Creek, but was as great as 250 mg/kg just above the confluence with the Cheyenne River. In the Cheyenne River, the concentration of arsenic in the bottom sediment was much smaller, about 20 mg/kg.

Dissolved arsenic in water can be a hazard if the concentration exceeds 50 micrograms per liter (μg/L) (Cherry and others, 1986). In Whitewood Creek, the dissolved arsenic concentration fluctuates seasonally and varied from about 20 μg/L in January of 1985 to 130 μg/L in August 1985 at the U.S. Geological Survey station about 4 km from the mouth of Whitewood Creek. Fuller and others (1987) measured 15 to 68 μg/L of dissolved arsenic in Whitewood Creek, 90 percent of which was arsenate. The greater concentrations of arsenic were found in Whitewood Creek where ground water was seeping into the stream. Mass balance calculations by Goddard and Wuolo (1987) comparing dissolved arsenic concentrations with estimated solid-phase mass stored in the floodplains suggest that it will take hundreds of years for all of the arsenic to be removed as dissolved arsenic.

Arsenic was also found in the ground water in the alluvial floodplain of Whitewood Creek. Goddard (1987) reported that between 50 and 500 μg/L of arsenic was found in the alluvial aquifer along Whitewood Creek. At the Sheeler Seeps, a location about 1 km from the confluence of Whitewood Creek and the Belle Fourche River, Rees and Ranville (1987) found 3,500 μg/L of dissolved arsenic in a sample of water that had percolated through the tailings but not through the more impermeable underlying shale bedrock. Cherry and others (1986) found arsenic concentrations of 1,100 and 2,300 μg/L in piezometer samples of ground water at the Sheeler seeps site. These samples were collected in the tailings and at the tailings-bedrock interface. They also found as much as 13,500 μg/L of arsenic in water collected in lysimeters in the tailings in the unsaturated zone at the Sheeler site. Water-supply wells in the alluvial valley but in locations where no discernable tailings were found contained very little arsenic. Concentrations of arsenic ranged from a low of 2 μg/L to a high of 46 μg/L in 11 well samples. All of the wells had arsenic concentrations below the Environmental Protection Agency (EPA) recommended maximum concentration (Cherry and others, 1986).

Cain and others (1987) studied the arsenic content of some benthic insects in Whitewood Creek and the Belle Fourche River. They found hydropsychid caddisflies at almost all of their sample sites. In Whitewood Creek above Lead, the arsenic concentration in the caddisflies was 3.1 micrograms per gram (μg/g) dry weight. At the Berger site, the concentration was 22.4 μg/g; at the Sheeler site, the concentration was 46.4 μg/g; in the Belle Fourche below the confluence of Whitewood Creek, the concentration was 26.3 μg/g; and, in the Belle Fourche above the Whitewood Creek confluence, the concentration was 1.7 μg/g. Using these sites, they determined that the concentration of arsenic in insects 73 km from the original source of mine waste was similar to concentrations just below the mine. This study indicates that arsenic may be entering the food chain through insects.

The ultimate destination of the sediment borne by the Cheyenne River and its tributaries is the Cheyenne River Arm of Lake Oahe. Lake Oahe is a large reservoir on the Missouri River created by Oahe Dam near Pierre, South Dakota (fig. 1). The Cheyenne River arm is a small part of the reservoir, but it is the part of the lake that is receiving the water and sediment from the Cheyenne River and, therefore, is the destination of the arsenic arising from the tailings in Whitewood Creek 300 km upstream. Thus, an important part of the surface water study is the fate of the arsenic once it reaches the reservoir. Is the arsenic likely to have an adverse effect on the aquatic life in the reservoir? Is the arsenic likely to affect the water quality of the reservoir? What actually does become of the arsenic in the reservoir sediment? Is the arsenic stored permanently in the reservoir bottom sediment or does it dissolve into the water?

Horowitz and others (1988) examined in detail the metal distributions in six cores of sediment collected from the bottom of the reservoir in 1985 (fig. 2). They found that arsenic was the only trace element among 14 that was anomalously high compared to concentrations found in the rocks surrounding the reservoir. Arsenic concentrations ranged from a low of 7 mg/kg to a high of 260 mg/kg. One core (6) apparently went deep enough to reach through sediment trapped since the closure of Oahe Dam; the core extended into the old riverbed or flood plain. Significant changes in the sediments and their associated metals were observed. The major change was a change in sediment-bound arsenic levels, which increased following closure of the dam.

Cores collected in 1985 showed a change from oxidizing to reducing conditions at 2 to 3 cm. (Horowitz and Elrick, 1987). However, the boundary was not reached until 12-13 cm depth in cores collected in 1986 near the mouth of the Cheyenne River. The oxidizing-reducing boundary occurred at 4-5 cm near the main body of Lake Oahe where the sedimentation rate was much smaller. Although 1985 was a dry year, 1986 was wet, accounting for the difference from one year to the next. Callender and Ficklin (1987), using phosphate, manganese, and iron profiles, estimated sedimentation rates of 12-13 cm per year at site 2 and 5-6 cm per year at site 6. The possibility exists that, due to the rapid sedimentation rate, the interstitial water chemistry has been preserved in the accumulated sediment. The biogeochemical reactions that produce the changes in the interstitial water had not yet had time to become established.

Arsenic concentrations found in the interstitial water are listed in table 1 as a function of increasing depth from the water-sediment interface. The depth at which the oxidizing-reducing interface was found is reflected by the arsenic concentration and by the ratio of arsenite to arsenate. In the oxidized zone, the concentration of arsenic was found to be low, from less than 5 µg/L to about 50 µg/L. This arsenic was mainly arsenate. On the other hand, in the reducing zone, arsenite was the most abundant form, and the overall concentration increased dramatically, to as great as 1,600 µg/L. It appears from these data that reducing conditions greatly increase the solubility of arsenic.

Callender and Ficklin (1987) calculated upward diffusion/sediment accumulation ratios and found that little interstitial arsenic is being recycled to the water column in the rapidly accumulating sediments (site 2) but that as much as 30 percent of the sedimentary arsenic may be recycled to the bottom water in the lower Cheyenne River Arm (site 6).

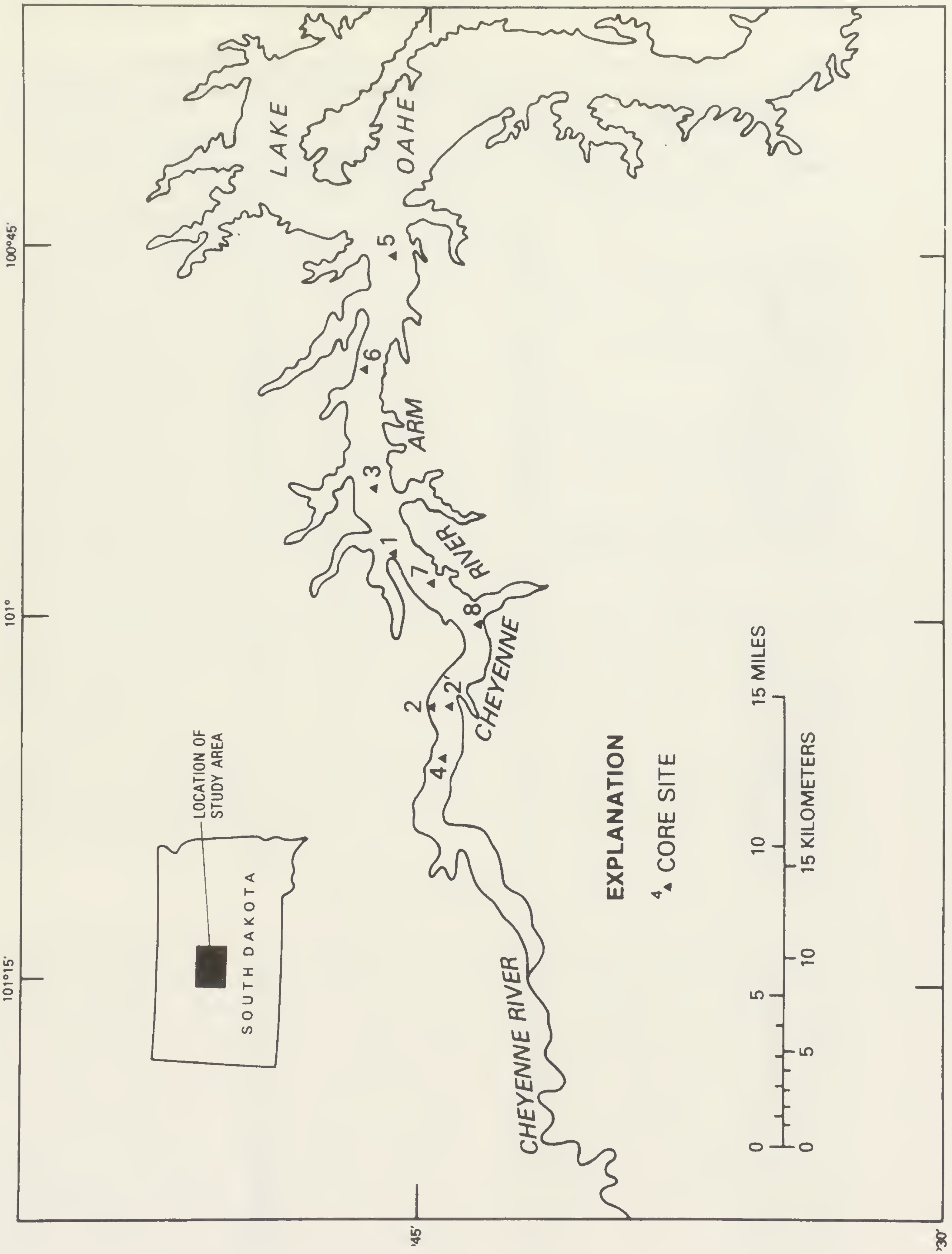

Figure 2. Location of sediment cores taken from the Cheyenne River arm, Lake Oahe, South Dakota.

Table 1.--Concentration of arsenic in interstitial water of selected cores, Cheyenne River arm of Lake Oahe, South Dakota

Sample interval	Arsenite (μg/L)	Arsenate (μg/L)
	core 2	
0-1 cm	<10	18
1-3 cm	<10	13
3-4 cm	<10	<10
6-8 cm	34	50
10-12 cm	70	120
12-13 cm	60	67
13-15 cm	55	120
17-19 cm	39	39
21-23 cm	50	53
25-27 cm	39	64
30-31 cm	39	44
	core 1	
1 0-1 cm	<10	<10
1-2 cm	<10	20
2-4 cm	26	12
6-8 cm	30	12
10-12 cm	70	31
14-16 cm	190	72
21.5-22 cm	26	23
25-27 cm	100	21
27-28 cm	210	115
31-33 cm	200	47
33-34 cm	250	75
	core 5	
0-1 cm	<10	<10
1-2 cm	<10	<10
2-4 cm	<10	<10
5-7 cm	470	90
7-9 cm	1040	215
11-13 cm	880	140
15-17 cm	880	110
70-72 cm	1610	390
72-74 cm	1380	500
75-77 cm	1860	350
86-88 cm	1410	180
88-89 cm	1410	280

Callender and Ficklin (1987) stated:

> During warm summer months the deep (30 to 40 m (meters)) water column stratifies and the thermocline is located near the bottom because of high prevalent winds. The environmental effect of the potentially large arsenic transport flux from the surficial sediment to this bottom water needs to be evaluated.

Arsenic can be extracted from solid-phase sediment by a moderately strong acid solution (4.0 N HCl), and the arsenic in the extract can be separated into arsenate and arsenite (Ficklin and Callender, 1987). The extraction is not complete, but the residual arsenic can be solubilized by reaction with a strong oxidizing solution of $KClO_3$ and HCl. The acid solution dissolves arsenic associated with reactive iron, and the strong oxidizing solution dissolves sulfide-bound arsenic.

Most of the arsenic in the sediment of the Cheyenne River Arm resides in the solid phase, and the oxidizing reducing conditions are reflected by the chemical state of the arsenic found, as determined using the chemical extractions described above. In the oxidized zone, the acid extraction produced only arsenate, leaving a small concentration of residual arsenic. On the other hand, in the reduced zones, some arsenate and some arsenite, but mostly sulfide-bound arsenic were found (table 2).

In sediment that is deeply buried, for instance, the material from core 5 at 70-72 cm, most of the arsenic resides in the sulfide phase (table 2). The reducing conditions tend to stabilize the arsenic as sulfides, but obviously the concentration of soluble arsenic increases concurrently.

The new analytical data produced by the U.S Geological Survey in this and in other studies, notably that of Cherry and others (1986), rather conclusively show that the arsenic in the Whitewood Creek-Belle Fourche River-Cheyenne River is mobilized by weathering reactions and may be entering the flood chain.

POSSIBLE REMEDIES

Whitewood Creek was placed on the United States Environmental Protection Agency's (EPA) list of priority hazardous waste sites on October 23, 1981 (Cherry and others, 1986). In December of 1983, Homestake Mining Company and the State of South Dakota petitioned the EPA for removal of Whitewood Creek from the National Priority List. At the time of this report, the status of the petition was uncertain. Cleanup of the tailings along Whitewood Creek may or may not occur.

One possible solution to the problem is to do nothing. The scientific evidence collected by the U.S. Geological Survey and by Cherry and others (1986) suggests that only limited long-term environmental damage may be occurring, especially in the Whitewood Creek area and in the Belle Fourche River near its confluence with Whitewood Creek. However, the ground-water contamination is restricted to locations very close to Whitewood Creek. The arsenic in Lake Oahe is not very mobile. Assuming that the tailings remain undisturbed, the threat of arsenic poisoning from the tailings may not be serious. However, monitoring of the system should be continued.

Another option, which is currently being explored by Homestake Mining and Goldstake Mining as a joint venture, is recycling of at least

Table 2. Concentration of arsenic in sediment of selected cores in the Cheyenne River arm of Lake Oahe, South Dakota

Sample interval	Arsenite mg/kg	Arsenate mg/kg	Sulfide-bound mg/kg
core 2			
0-1 cm	<.5	4.9	<.5
1-3 cm	<.5	16	<.5
3-4 cm	<.5	7.7	3.0
6-8 cm	<.5	8.8	3.0
10-12 cm	7.8	12	5.0
12-13 cm	5.0	21	<.5
13-15 cm	4.5	20	9.4
17-19 cm	1.7	11	3.0
21-23 cm	3.6	15	6.0
25-27 cm	8.1	15	11
30-31 cm	2.0	8.1	6.0
core 1			
0-1 cm	<.5	5.6	3.8
1-2 cm	<.5	9.7	4.2
2-4 cm	<.5	21	<.5
6-8 cm	<.5	12	4.2
10-12 cm	4.1	13	2.9
14-16 cm	6.0	13	3.8
21.5-22 cm	8.0	38	<.5
25-27 cm	2.3	4.1	6.5
27-28 cm	5.4	2.1	6.5
31-33 cm	11	12	3.1
33-34 cm	7.9	2.3	8.0
34-36 cm	16	12	13
core 5			
0-1 cm	<.5	8.7	<.5
1-2 cm	<.5	8.8	<.5
2-4 cm	<.5	23	<.5
5-7 cm	9.4	5.3	<.5
7-9 cm	8.0	7.6	7.0
11-13 cm	28	15	10
15-17	10	12	8.0
70-72 cm	25	10	100
72-74 cm	25	5.0	3.0
75-77 cm	31	6.5	33
86-88 cm	29	5.9	83
88-89 cm	33	5.3	35

part of the mine waste to recover gold that was not extracted from the tailings in the first ore processing. Officials of both companies state that no actual moving of tailings is imminent. The venture is being treated as if it were a newly discovered ore deposit. Hence, any and all regulations of the State of South Dakota and Federal agencies would apply. As of May 1, 1989, the mining companies are still exploring the feasibility of the proposed gold recovery. The primary concern of the companies is a profitable venture. If there is sufficient gold in the tailings to warrant mining, then some of the environment of Whitewood Creek would be changed.

According to Grover (1987):

> Under the proposal, Goldstake would remove tailings deposits along the banks of Whitewood Creek and bury them in a tailing impoundment after extracting gold left in them from earlier mining. The impoundment would be in a 25-acre natural basin with an impermeable shale base. At the end of the project, topsoil and vegetation would cover the tailing.

If the venture proceeds a few pertinent issues still need to be addressed. In moving the tailings with a backhoe or some other digging device, will there be a burst of arsenic-bearing sediments entering the river system? Will the "equilibrium" situation that now exists be disturbed? Will the amount of arsenic in the river system diminish with the removal of much of the source material? Are existing environmental laws sufficient to regulate the removal of the tailings? These and other questions should be answered if the tailings are to be disturbed.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

EVALUATION OF SELECTED PHOSPHATE SOURCES FOR THE CONTROL OF ACID PRODUCTION FROM PYRITIC COAL OVERBURDEN

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ABSTRACT

Acid Mine Drainage (AMD) is a serious and pervasive threat to surface and groundwater quality in the eastern Appalachian coal regions and at area coal mines in the western United States. Recent research has indicated that the use of phosphate materials can be an effective treatment for the amelioration of AMD. Phosphate is effective at immobilizing iron and inhibiting the production of acid associated with the oxidation of FeS_2.

Four phosphate sources were tested for application rate determination utilizing a replicated soxhlet leaching technique described by Renton et al (1988a). These included two apatite ores (Cominco ore and Texas Gulf ore) at an application rate of 3% by weight apatite and two byproducts of the phosphate industry (Cominco waste and Staufer sludge) at rates of 1%, 3% and 5% apatite by weight. The Cominco and Staufer sources were procured from the Cominco Fertilizer Company in Garrison, Montana, and the Staufer Chemical Company (now Rhone-Poulence) in Silver Bow, Montana, respectively. Texas Gulf ore was obtained from Texas Gulf Chemical in Aurora, North Carolina.

Results of leachate analyses indicate that all sources at all rates of application resulted in significant decreases in titratable acidity versus a control. Acidity reductions ranged from a low of 7% for samples treated with Cominco waste (1%) to a high of 67% for Texas Gulf ore-treated samples. Texas Gulf ore, Staufer sludge (1%, 3% and 5%) and Cominco waste (1%, 3% and 5%) significantly reduced iron (Fe) concentrations in leachate, with Staufer sludge (5%) and Texas Gulf ore producing the most notable diminutions (62% and 63%, respectively). Maximum decreases in sulfate (SO_4^{2-}) concentrations of 26%, 20% and 25% were achieved by applications of Texas Gulf ore and Staufer sludge (3% and 5%), respectively. The more effective overall performance of the Staufer sludge and Texas Gulf ore can be attributed to the considerably greater relative surface area and P solubility of these amendments. Results of a scanning electron microscope examination of amendments corroborate these findings.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

GROWTH OF PLANTS ON INORGANIC SUPERFUND SITES

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ABSTRACT

Five unique waste/tailings materials were identified in the Silver Bow Creek Superfund area. Laboratory analyses and glasshouse studies identified chemical amendments and plant species suitable for further evaluation in field trials.

Two legumes and 21 grass species were seeded or planted in these amended hazardous inorganic wastes. The amendments were incorporated by three different techniques; deep injection into the seedbed, deep plowing, or by agricultural plowing. A more expensive coversoil wedge was also used in the study. Response of the grasses during the first growing season, as revealed by cover measurements, was very good. Legumes did not germinate and establish as well as the grasses. While successful species could not be identified after only one growing season, it was obvious that certain treatments ameliorated the phytotoxic properties of the wastes better than others, and some species performed better than others.

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INTRODUCTION

The phytotoxicity of any plant environment including the root medium is relative. Because of the genetic plasticity within plant species, different populations have evolved mechanisms to permit them to grow and reproduce in almost every conceivable environment. There are many plant species that can grow in a loam soil in Tennessee. A smaller number of species can complete their life cycles in a soil in Alberta, and there are fewer plant species that can germinate, establish, and grow on a windswept alpine ridge in Montana. But, in any unfavorable environment there are usually some plants that will complete their life cycles and perpetuate their species on that site. This is also true with respect to environments created by man. In most man-made environments, as in most natural environments, there are a few plant species that can germinate, establish, and survive. Occasionally we may be forced to manipulate the root media or otherwise ameliorate the environment to artificially stimulate plant performance, but it is the rare environment which cannot be vegetated by one means or another.

Acid generating soils represent one of the more inhibitory environments to plant survival and reproduction. The "cat clays" of the Netherlands or the Bear Paw shales of northeastern Montana represent natural acid generating plant growth materials. Acid generating, inorganic waste disposal sites represent a similar category of plant growth materials, but one created by man. Some of these are today called "hazardous waste sites". These superfund sites represent a particularly hostile environment to plant growth and survival. While many assume that these materials cannot support plant life, these "hazardous" wastes are more appropriately viewed as simply another environment hostile to plant germination, establishment, and survival.

As part of the Remedial Investigation/Feasibility Study on the Silver Bow Creek superfund site, the Reclamation Research Unit is investigating the potential of different mining wastes along Silver Bow Creek to support plant growth. This program and the results of the first growing season are the topic of this paper.

DESCRIPTION OF THE STUDY

This investigation is referred to as "STARS" or the Streambank Tailings and Revegetation Study. It was initiated to determine if vegetation could be grown on mining wastes deposited along the Silver Bow Creek floodplain. It is part of a larger superfund study being carried out in this area.

Surface soils along 27 miles of Silver Bow Creek have been polluted by tailings and mining wastes since the last century. These materials were deposited directly in the stream channel by mining or smelting operations or by the erosion of tailings or waste impoundments and subsequent deposition on the floodplain. In some instances, native soils have been covered with the wastes carried by flood waters, at other sites the soils and wastes were mixed together. Most of these materials contain pyrite and elevated metal levels. The oxidation of the pyrite has increased the acidity and liberated many of the metals in the wastes. The resulting streamside deposits are, therefore, usually acid and reveal elevated levels of several potentially harmful metals (i.e. lead, cadmium, copper, zinc, arsenic, etc.). These wastes range from coarse textured, sandy or gravelly materials to fine textured slimes. The deposits may be a few centimeters or a few meters thick. In some areas along the stream there are not visible mining related wastes, in others, the wastes stretch back from the stream channel for over 100 m.

Vegetation growing on the materials reflects the acid generating capacity, the depth of tailings or waste, other soil problems (i.e. salinity, nutrient deficiencies, water holding capacity, texture, etc...) and land use. Where the water table is within a few centimeters of the soil surface, one or two grasses may colonize the area. These grasses, tufted hairgrass (*Deschampsia caespitosa*) and colonial bentgrass (*Agrostis tenuis*) can tolerate extreme acidity (pH 3.2) and elevated concentrations of several metals (zinc, copper, aluminum). Other, drier sites may support woody shrubs that are actually rooted in native soils below the phytotoxic wastes. Several plant species can tolerate lightly polluted materials composed of mixtures of native soils and mining related wastes, but these plants grow more slowly than their counterparts on non-polluted soils. Heavy grazing tends to kill or severely retard this vegetation. Of major concern are non-vegetated soils between the tufted hairgrass/colonial bentgrass community and the vegetated rangeland soils not severely contaminated by tailings or wastes. This area comprises the major portion of the wastes/tailings deposits along Silver Bow Creek.

Five unique materials were selected as representative of the wastes/tailings along Silver Bow Creek (Schafer & Associates, et al. 1989a). A field site was selected as representative of each of these wastes and bulk samples were collected from each site. The response of each of these materials to amendments was evaluated in soil column studies in the laboratories of the Reclamation Research Unit at Montana State University. Combinations of wastes/tailings and amendments which produced the most favorable response (as determined by reduced acidity and metal availability) were evaluated with numerous plant species under glasshouse conditions. (Reclamation Research Unit, et al. 1989).

In general, combinations of calcium carbonate ($CaCO_3$), calcium hydroxide ($Ca(OH)_2$), ferric sulfate ($FeSO_4$) and phosphate fertilizer reduced the concentrations of most metals in the leachate from the soil columns and/or permitted plant growth in the glasshouse. Unique combinations of these amendments were incorporated into the materials at each of the previously selected five sites. Three amendment incorporation methods, a topsoil wedge, and a control were investigated. The amendment incorporate methods included:

- standard agricultural tillage; mixing to a depth of 15 to 20 cm;
- deep mechanical plowing; mixing to a depth of 1.2 m; and
- lime slurry injection; forcing amendments into the wastes to a depth of 1.2 m or the depth of the waste.

The coversoil wedge over standard agricultural tillage completed the treatments. On two of the study sites a second amendment mixture was used on one plot. Full discussion of these amendments may be found in Schafer & Associates, et al. 1989b).

AMENDMENTS

Research plots were amended during August-September, 1988. Amendments and application rates are shown in Table 1. Seeding was to be carried out immediately, however, pH values on some of the treatments reached 11.5. Seeding was delayed until chemical reactions between the amendments, wastes/tailings, and water reduced seedbed pH values below 8.5.

Fertilizer additions were based upon analyses of materials from each site and varied from site to site and within sites. Fertilizer amendments included nitrogen, phosphorus, potassium, and boron. The fertilizers were surface applied after amendment mixing and were rototilled into the top of 15 to 20 cm of soil.

SEEDING

The study sites were located in a cool, dry, windy, high elevation area (1,500 m). Plant species used in this investigation (Table 2) were selected to compliment the climate of the area and soils of the sites. Tolerance to acid was also important in species selection. Various wastes expressed other attributes such as high salinity and variable textures; plant species selection addressed these characteristics. While the amended materials were no longer acid, due to an inability to thoroughly mix amendments with the rooting material, the presence of acid materials beneath the zone of amendment and residual pyrite in the wastes; acid tolerance continues to be important to revegetation.

Spring precipitation and summer drought are the rule in the study area, therefore, acid tolerant cool season grasses composed the major portion of each seed mix. Soil textures varied from heavy silty clays (45% silt, 21% clay) to sandy (86% sand), and two of the sites were saline (EC 6.7 and 7.5 μm/cm). Plants selected for the saline sites were salt tolerant in addition to acid and drought tolerant. Species selected for the silty clays and those selected for the sandy sites were adapted to these textures. Within the range of known grass tolerances, species selected for each site were adapted to the unique characteristics of that site. For example, the grass species selected for the sandy soils of Site 7 were chosen for drought and acid tolerance, good performance on coarse textured materials, and tolerance to prolonged subzero temperatures with little or no snow cover. Grasses chosen for seeding on the other sites met similar selection criteria. Since several grasses possessed the genetic potential to germinate, establish, and reproduce in these environments, two seed mixes were for each site (Table 2).

Table 1. Amendments and rates for each site, STARS. Autumn, 1988.

		Fertilizer (kg/ha)			
Site/Plot	Amendment*	N	P_2O_5	K_2O	B
2	Lime**, phosphogypsum, ferric sulfate	56	56	84	1.7
Extra Plot	$Ca(OH)_2$	56	56	84	1.7
7	Lime**	56	56	84	1.7
21	Lime**, phosphogypsum, Plot 1-3	34	56	84	1.7
	and ferric sulfate Plot 4	56	56	84	1.7
27	Lime** and ferric sulfate	34	56	0	1.7
Extra Plot	Lime** and triple superphosphate	34	56	0	1.7
33	Lime** and phosphogypsum	34	56	84	1.7
All topsoil wedges		56	56	0	1.7

* Specific amendment rates were calculated for each individual plot. See Schafer & Associates, et al. for full detail.

** Refers to unique combinations of $CaCO_3$ and CaO.

Table 2. Vegetation seeded or sprigged at each STARS site.

Site	Seed Mix	Scientific Name Genus, Species, Cultivar	Common Name	Rate* (PLS/sq. meter)
2	1	*Agropyron elongatum* Orbit	Tall wheatgrass	215
		Agropyron riparium Sodar	Streambank wheatgrass	215
		Agropyron intermedium Greenar	Intermediate wheatgrass	215
		Distichlis spicata	Saltgrass	10 sprigs/plot
		Lotus corniculatus Tretana	Birdsfoot trefoil	215
		Deschampsia caespitosa	Tufted hairgrass	7 plants/plot
	2	*Agropyron trichophorum* Greenleaf	Pubescent wheatgrass	215
		Agropyron trachycaulum Revenue	Slender wheatgrass	215
		Sitanion hystrix	Bottlebrush squirreltail	215
		Elymus junceus Swift	Russian wildrye	215
		Melilotus officinalis	Yellow sweetclover	215
7	1	*Festuca ovina* Covar	Sheep fescue	161
		Poa compressa Reubens	Canada bluegrass	161
		Calamovilfa longifolia Goshen	Prairie sandreed	108
		Elymus augustus	Altai wildrye	108
		Agropyron dasystachyum Critana	Thickspike wheatgrass	108
		Melilotus officinalis	Yellow sweetclover	108
	2	*Festuca longifolia* Durar	Hard sheep fescue	161
		Deschampsia caespitosa	Tufted hairgrass	161
		Elymus giganteus Volga	Mammoth wildrye	108
		Elymus cinereus Magnar	Basin wildrye	108
		Agropyron dasystachyum Critana	Thickspike wheatgrass	108
		Lotus corniculatus Tretana	Birdsfoot trefoil	108
21	1	*Agropyron elongatum* Orbit	Tall wheatgrass	161
		Agropyron cristatum Ephraim	Crested wheatgrass	161
		Agropyron riparium Sodar	Streambank wheatgrass	161
		Distichlis spicata	Saltgrass	10 sprigs/plot
		Lotus corniculatus Tretana	Birdsfoot trefoil	108
		Deschampsia caespitosa	Tufted hairgrass	7 plants/plot
	2	*Agropyron intermedium* Greenar	Intermediate wheatgrass	161
		Agropyron desertorum Nordan	Crested wheatgrass	161
		Agropyron trichophorum Greenleaf	Pubescent wheatgrass	161
		Elymus junceus Swift	Russian wildrye	161
		Melilotus officinalis	Yellow sweetclover	108

Table 2. Continued.

Site	Seed Mix	Scientific Name Genus, Species, Cultivar	Common Name	Rate* (PLS/sq. meter)
27	1	*Agropyron desertorum* Nordan	Crested wheatgrass	215
		Agropyron smithii Rosana	Western wheatgrass	161
		Agropyron trichophorum Greenleaf	Pubescent wheatgrass	161
		Elymus augustus	Altai wildrye	108
		Lotus corniculatus Tretana	Birdsfoot trefoil	108
	2	*Agropyron cristatum* Ephraim	Crested wheatgrass	215
		Agropyron elongatum Orbit	Tall wheatgrass	161
		Agropyron intermedium Greenar	Intermediate wheatgrass	161
		Elymus junceus Swift	Russian wildrye	108
		Medicago sativa	Alfalfa	108
33	1	*Agropyron smithii* Rosana	Western wheatgrass	161
		Elymus cinereus Magnar	Basin wildrye	108
		Poa compressa Reubens	Canada bluegrass	161
		Agropyron trachycaulum Revenue	Slender wheatgrass	108
		Melilotus officinalis	Yellow sweetclover	108
	2	*Elymus augustus*	Altai wildrye	108
		Deschampsia caespitosa	Tufted hairgrass	161
		Agropyron trichophorum Greenleaf	Pubescent wheatgrass	161
		Agropyron riparium Sodar	Streambank wheatgrass	108
		Lotus corniculatus Tretana	Birdsfoot trefoil	108

* PLS - Pure Live Seed.

Commercial availability is important in any large scale revegetation program. Species selected for seeding, with minor exceptions, were only chosen if seed was commercially available. Two species of the more than twenty varieties selected for this study were not available from retail seed outlets. *Deschampsia caespitosa* (tufted hairgrass) seeded on two of the study sites was an experimental variety supplied by the Jacklin Seed Company for research purposes. They anticipate that this seed will be available before initiation of any remediation programs at the Superfund site. The second species, *Distichlis spicata* (saltgrass) is not available as seed, but sprigs may be propagated in a glasshouse and transplanted as containerized stock if used in any rehabilitation program.

Seeding and planting were carried out during early spring, 1989. All seed was broadcast into a roughened seedbed, raked, rolled, and mulched. The oat straw mulch was crimped into the seedbed. The mulch was intended to reduce wind velocities around the seedlings.

RESULTS

The objectives of the vegetation portion of the STARS study were to identify plant species that will:

1) germinate, establish, and survive in the harsh environment;
2) provide enough above ground cover and below ground production to stabilize the root zone materials; and
3) harvest water from the wastes/tailings.

Two phenomena directly influenced seedling success in this study.

1. The mulch (oat straw) contained a large number of oat seeds. These seeds germinated and produced an oat crop at all sites. The annual grain provided excellent protection for seeded species during the critical seedling stage.

2. Temperature and precipitation during the 1989 growing season were near normal. Rainfall was optimally distributed for plant survival. Normal summer drought occurred, but was not severe enough to kill health plants. Temperatures were also moderate during the early seedling establishment period.

PLANT DENSITY

Plant density, a measure of seed germination and seedling survival at a specific point in time, was measured on all field plots between July 10 and 14, 1989. One 50 x 50 cm microplot was established in a representative location within each field plot, and the number of emerging seedlings were counted and recorded. This was not intended to be a scientific evaluation, but a fast screening of the sites to establish that the seeded grasses and legumes had germinated and established. Due to the lack of maturity of the vegetation, individual species could not be identified. Life forms were therefore recorded in three categories: seeded legumes, seeded grasses, and non-seeded species. Tables 3 through 7 exhibit mean plant density for vegetation growing on each treatment at the five sites.

In general, seeded vegetation growing on the coversoil wedges exhibited the greatest density, followed by plots in which the amendments were incorporated using the deep plow. Field plots in which amendments were incorporated using the injection method supported seeded vegetation densities similar to the agriculture treated plots. The vegetation density measurements showed adequate to good establishment of seeded grasses on most treatment plots. Seeded legumes had poor to adequate establishment in the amended plots. Treatment and species differences were evident.

CANOPY COVERAGE

Percent aerial canopy cover was estimated at peak growth using two 20 x 50 cm microplots established in representative locations within each plot. The aerial cover was estimated using the procedures outlined by Daubenmire (1970) and values were recorded during the week of August 21, 1989. Tables 8 through 12 exhibit mean percent aerial cover for vegetation growing on each treatment at the five STARS sites. The data are arranged by amendment incorporation treatment and the plant classes - seeded legumes, seeded grasses, non-seeded grasses, and non-seeded weedy forbs. Total aerial cover is also shown.

The cover data confirmed trends demonstrated by the earlier evaluation of plant density. That is, vegetation growing on the coversoil wedges exhibited the greatest cover, followed by plants growing on plots in which the chemical amendments were incorporated with the deep plow. The cover estimates showed adequate to good establishment for seeded grasses, and poor to fair establishment for seeded legumes on most plots. Seed mix differences as well as treatment differences were noted.

SPRIGGED VEGETATION

At the time of field seeding, tufted hairgrass and saltgrass were transplanted into the treatment plots at STARS Sites 2 and 21. These plants had been propagated in the glasshouse from specimens collected near these sites. Table 13 summarizes the response of these plants to the treatments. Each plant was visually inspected and an assessment of its overall health and vigor was numerically scored from 1 (dead) to 5 (vigorous and robust growth).

The saltgrass performed better at both sites on the "deep plow" treatment. Tufted hairgrass also performed well on this treatment. The lack of better growth of these species on the coversoil wedges may be due to the sandy texture of the root medium and shading by other species.

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APPENDIX I

Table 3. Mean seedling density (number of plants/m^{-2}) at STARS Site 2 (Manganese Stockpile).

Treatment	Seeded Species		Non-Seeded Species
	Legumes	Grasses	Grasses and Forbs
Seed Mix Number 1*			
Deep Plow	10	84	59
Injection	17	94	92
Extra	14	152	77
Control	2	42	9
Agricultural	3	85	88
Coversoil			
@ 15 cm	22	183	101
@ 38 cm	10	244	146
Seed Mix Number 2*			
Deep Plow	19	116	62
Injection	4	76	90
Extra	5	91	52
Control	0	2	6
Agricultural	17	89	52
Coversoil			
@ 15 cm	45	154	70
@ 38 cm	50	171	99

Table 4. Mean seedling density (number of plants/m^{-2}) at STARS Site 7 (Rocker).

Treatment	Seeded Species		Non-Seeded Species
	Legumes	Grasses	Grasses and Forbs
Seed Mix Number 1*			
Deep Plow	1	32	106
Injection	1	26	61
Control	0	2	12
Agricultural	10	35	102
Coversoil			
@ 15 cm	95	115	116
@ 38 cm	65	80	137
Seed Mix Number 2*			
Deep Plow	0	33	119
Injection	0	8	19
Control	0	2	6
Agricultural	1	36	83
Coversoil			
@ 15 cm	81	101	88
@ 38 cm	81	74	130

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* One 50 cm x 50 cm frame/treatment-plot; number of observations = 4.

Table 5. Mean seedling density (number of plants/m^{-2}) at STARS Site 21 (Ramsay Flats).

Treatment	Seeded Species		Non-Seeded Species
	Legumes	Grasses	Grasses and Forbs
Seed Mix Number 1*			
Deep Plow	9	133	111
Injection	0	57	110
Control	0	0	0
Agricultural	2	81	194
Coversoil			
@ 15 cm	52	217	173
@ 38 cm	44	153	239
Seed Mix Number 2*			
Deep Plow	15	150	107
Injection	18	126	188
Control	0	0	0
Agricultural	1	57	204
Coversoil			
@ 15 cm	75	250	182
@ 38 cm	55	178	242

Table 6. Mean seedling density (number of plants/m^{-2}) at STARS Site 27 (Flooded Agriculture Land).

Treatment	Seeded Species		Non-Seeded Species
	Legumes	Grasses	Grasses and Forbs
Seed Mix Number 1*			
Deep Plow	0	119	116
Control	0	23	20
Agricultural	0	71	68
Extra	0	67	44
Seed Mix Number 2*			
Deep Plow	0	111	136
Control	0	3	13
Agricultural	0	108	51
Extra	0	51	70

* One 50 cm x 50 cm frame/treatment-plot; number of observations = 4.

Table 7. Mean seedling density (number of plants/m^{-2}) at STARS Site 33 (Opportunity).

Treatment	Seeded Species		Non-Seeded Species
	Legumes	Grasses	Grasses and Forbs
Seed Mix Number 1*			
Deep Plow	3	17	96
Injection	0	6	100
Control	0	0	10
Agricultural	0	6	54
Coversoil			
@ 15 cm	46	53	130
@ 38 cm	117	53	110
Seed Mix Number 2*			
Deep Plow	2	73	77
Injection	0	59	105
Control	0	0	4
Agricultural	0	17	40
Coversoil			
@ 15 cm	49	185	98
@ 38 cm	91	188	94

APPENDIX II

Table 8. Mean percent aerial cover of vegetation at STARS Site 2 (Manganese Stockpile).

Treatment	Seeded Species		Non-Seeded Species		Total
	Legumes	Grasses	Grasses	Forbs	
Seed Mix Number 1*					
Deep Plow	0.6	2.8	5.3	0.0	8.7
Injection	0.0	4.3	6.0	0.0	10.3
Extra	0.3	3.8	5.4	0.0	9.5
Control	0.0	0.3	0.9	0.0	1.2
Agricultural	0.0	4.9	1.9	0.0	6.8
Coversoil					
@ 15 cm	7.4	16.0	16.3	0.0	39.7
@ 38 cm	5.9	21.4	22.0	0.0	49.3
Seed Mix Number 2*					
Deep Plow	0.5	1.0	5.6	0.0	7.1
Injection	0.4	3.3	7.3	0.0	11.0
Extra	0.1	4.4	5.6	0.0	10.1
Control	0.0	0.0	0.0	0.0	0.0
Agricultural	0.0	2.4	4.0	0.0	6.4
Coversoil					
@ 15 cm	26.9	24.0	15.8	0.0	66.7
@ 38 cm	26.8	28.1	17.2	0.0	72.1

Table 9. Mean percent aerial cover of vegetation at STARS Site 7 (Rocker).

Treatment	Seeded Species		Non-Seeded Species		Total
	Legumes	Grasses	Grasses	Forbs	
Seed Mix Number 1*					
Deep Plow	1.3	14.9	18.8	0.8	35.8
Injection	1.6	6.5	7.9	0.4	16.4
Control	0.0	0.4	2.0	0.0	2.4
Agricultural	9.3	13.9	13.6	0.0	36.8
Coversoil					
@ 15 cm	51.0	18.6	38.3	1.1	109.0
@ 38 cm	28.5	8.8	48.5	2.1	87.9
Seed Mix Number 2*					
Deep Plow	0.3	15.6	19.6	1.0	36.5
Injection	0.0	5.0	0.9	0.0	5.9
Control	0.0	0.3	1.5	0.0	1.8
Agricultural	1.1	26.8	12.6	0.0	40.5
Coversoil					
@ 15 cm	61.9	16.6	42.6	5.0	126.1
@ 38 cm	27.5	13.1	47.3	2.6	90.5

* Two 20 cm x 50 cm frames/treatment-plot; number of observations = 8.

Table 10. Mean percent aerial cover of vegetation at STARS Site 21 (Ramsay Flats).

Treatment	Seeded Species		Non-Seeded Species		Total
	Legumes	Grasses	Grasses	Forbs	
Seed Mix Number 1*					
Deep Plow	0.1	11.0	8.6	0.0	19.7
Injection	0.0	3.5	5.1	0.0	8.6
Control	0.0	0.0	0.1	0.0	0.1
Agricultural	0.0	5.8	9.8	0.0	15.6
Coversoil					
@ 15 cm	9.6	14.6	26.3	3.3	53.8
@ 38 cm	3.8	10.5	30.0	4.1	48.4
Seed Mix Number 2*					
Deep Plow	0.3	16.3	8.6	0.0	25.2
Injection	0.0	5.8	8.3	0.0	14.1
Control	0.0	0.0	0.1	0.0	0.1
Agricultural	0.0	8.0	10.4	0.0	18.4
Coversoil					
@ 15 cm	9.6	16.6	32.5	2.4	61.1
@ 38 cm	4.4	11.6	26.9	11.0	53.9

Table 11. Mean percent aerial cover of vegetation at STARS Site 27 (Flooded Agricultural Land).

Treatment	Seeded Species		Non-Seeded Species		Total
	Legumes	Grasses	Grasses	Forbs	
Seed Mix Number 1*					
Deep Plow	0.0	15.8	24.8	0.0	40.6
Extra	0.0	17.4	5.5	0.0	22.9
Control	0.1	5.4	3.6	0.0	9.1
Agricultural	0.0	22.9	14.1	0.1	37.1
Seed Mix Number 2*					
Deep Plow	0.0	12.4	25.6	0.0	38.0
Extra	0.0	14.4	9.0	0.4	23.8
Control	0.0	0.9	0.9	0.0	1.7
Agricultural	0.0	15.1	15.9	0.0	31.0

* Two 20 cm x 50 cm frames/treatment-plot; number of observations = 8.

Table 12. Mean percent aerial cover of vegetation at STARS Site 33 (Opportunity).

Treatment	Seeded Species		Non-Seeded Species		
	Legumes	Grasses	Grasses	Forbs	Total
Seed Mix Number 1*					
Deep Plow	1.0	10.1	12.0	2.4	25.5
Injection	0.1	1.0	11.8	1.6	14.5
Control	0.0	0.0	0.1	4.5	4.6
Agricultural	0.5	0.4	3.6	5.0	9.5
Coversoil					
@ 15 cm	32.8	9.3	20.8	2.6	65.5
@ 38 cm	19.5	9.1	21.1	7.6	57.3
Seed Mix Number 2*					
Deep Plow	0.3	23.5	11.8	4.8	40.4
Injection	0.0	11.0	10.5	1.3	22.8
Control	0.0	0.0	0.1	5.1	5.2
Agricultural	0.1	2.9	3.0	2.4	8.4
Coversoil					
@ 15 cm	29.0	38.0	18.1	1.4	86.5
@ 38 cm	25.3	28.5	23.3	0.0	77.1

* Two 20 cm x 50 cm frames/treatment-plot; number of observations = 8.

Table 13. Response of sprigged vegetation at STARS Site 2 (Manganese Stockpile) and STARS Site 21 (Ramsay Flats).

Treatment**	Mean Response Ranking*			
	Species			
	Saltgrass		Tufted Hairgrass	
	Site 2	Site 21	Site 2	Site 21
Deep Plow	3.3	2.8	3.3	3.8
Injection	2.9	2.1	4.0	3.7
Extra	3.1		3.4	
Control	1.4	1.4	3.3	1.5
Agricultural	2.1	2.0	3.0	3.7
Coversoil	2.7	1.1	3.5	2.9

* Numerical ranking based on visual inspection: 1=dead plant; 2= barely alive; 3= alive; 4=rapidly growing; 5=vigorous and robust growth.

** N=4; based on the four field replications. Each replication is an evaluation of 10 plants for saltgrass and 7 plants for the tufted hairgrass.

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EARLY PERFORMANCE OF VARIOUS NATIVE AND INTRODUCED GRASSES AND FORBS ON THE CHEROKEE COUNTY, KANSAS, SUPERFUND SITE

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ABSTRACT

The mining of lead and zinc sulfides began in Cherokee Co., KS in 1876 and continued through 1970. As a result of this shallow underground mining, chat wastes were either deposited on the soil surface or as mine waste piles. In 1983, the U.S. Environmental Protection Agency (EPA) added 284.9 km^2 of Cherokee County to the National Priorities List due to the risks to human health and the environment by the abandoned lead-zinc mines. The Cherokee County Superfund Site was divided into six subsites for investigation and remediation. This Bureau of Mines' study was conducted on the chat wastes located within the Galena subsite in southeastern Kansas which incorporates 46.6 km^2 and includes the city of Galena.

Two experimental areas, each 105 by 60 m, were utilized in this study. One experimental area was designated native soil material (Nixa series), while the second area consisted of leveled chat. Each area was prepared prior to experimental treatment by removing the larger rock fragments by rock raking followed by disking. Both experimental areas were limed and fertilized based on soil test results. A randomized complete block design was utilized with 7 replicates in each experimental area. Thirty 3 by 6 m plots were installed in each of the replicates: included were 2 control plots, 15 grass species trial plots, and 13 forb species trial plots. Each species was randomly assigned to a plot within each replicate. Species tested included introduced or native and cool or warm season grasses, non-leguminous forbs, and leguminous forbs. The results indicate that the native warm season grasses seeded on the chat waste material had the best emergence of any of the species tested during the initial growing season.

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INTRODUCTION

Since its establishment in 1910, the Bureau of Mines has had as its mission the unique responsibility of helping to assure the nation of an adequate and dependable supply of mineral materials at acceptable economic, environmental, and social costs. With the recent shift in national emphasis to regulations and environmental issues, the Bureau has kept pace by reorganizing its research effort and creating two new divisions (Veith and Kaas, 1988). The Office of Regulatory Projects Coordination provides a focal point on regulatory affairs affecting the minerals industry, and the Division of Environmental Technology (ET) conducts mineral-related environmental research from nine Bureau research centers located strategically across the country.

Environmental Technology is concerned with mineral-related liquid and solid waste management and also administers the Abandoned Mine Land and National Mine Land Reclamation Center programs of the federal government. A major concern of the Bureau's environmental technology program is the stabilization of solid wastes produced by the minerals industry, as these materials account for 80 percent of the nation's nonagricultural, land-disposed solid wastes (Veith and Kaas, 1988).

In the mid-1980's, a major effort was begun by the Bureau to research problems associated with solid waste stabilization in the primary waste-producing sectors of the minerals industry. In addition to increasing these in-house environmental efforts, the Bureau offered its mining expertise to the U.S. Environmental Protection Agency (EPA), to assist them in their Superfund remedial action activities.

Cherokee County, Kansas, is one EPA Region VII Superfund site in which the Bureau is assisting the EPA in it's site remediation process. Not only is Cherokee County an active Superfund Site, but it is also the location of a Bureau in-house revegetation research project. The initial phase of this revegetation research project is a large species trial experiment conducted on abandoned lead-zinc mining related waste material and an undisturbed native soil adjacent to the mine waste material. The objectives of this experiment are to evaluate and compare the performance of 15 grass and 13 forb species seeded directly onto the mine waste material and soil amended with a one-time only application of nitrogen (N)-phosphorus (P)-potassium (K) fertilizer and agricultural lime. Species tested included introduced or native and cool or warm season grasses, non-leguminous forbs, and leguminous forbs. This paper summarizes the first-year revegetation efforts, the chemical characteristics of the mine waste material and adjacent undisturbed soil, problems encountered, and future Bureau plans for the revegetation of Cherokee County, Kansas.

Background Information

Ore was first discovered in the Tri-State Mining District of Oklahoma, Kansas, and Missouri in 1848 (EPA Record of Decision, 1989). Mining began in Kansas in 1876, where the first operation was in the city of Galena. Sphalerite (zinc sulfide) and galena (lead sulfide) were the major economic minerals, with cadmium being produced as an important by-product of the smelting operation. Pyrite and marcasite (both iron disulfides) made up about five percent of the minerals in the Galena area.

Ore deposits in the Galena area were shallow, generally occurring from surface outcrops to depths of 30.4 meters. Access to the ore and exploration of the deposits were through vertical shafts, and mine development progressed outward in a modified room and pillar pattern to follow the ore vein. If an exploration shaft failed to intersect ore, the miner would simply move over a few meters on the small claim and try again. As a result, the mineralized portion of the Tri-State District is covered with thousands of shallow shafts, some culminating in mined-out areas and some dead-ending in waste material.

Geologically, Galena resides in the Ozark Plateau Provence of Kansas, which developed on cherty limestone of the Mississippian age. Much of the area is mantled with residual cherty gravel, the result of limestone weathering, and exhibits thin and rocky soils. Local relief exceeds 50 meters, with an overall relief of the Kansas Tri-State District slightly in excess of 82 meters. These characteristics, together with numerous steep slopes, combine to make much of the area unsuitable for cropland. Deciduous hardwood forests cover most of the hillsides, while the uplands contain large clearings devoted to livestock grazing. Cropland is primarily located in the valley floors.

Between 1876 and 1970, the Kansas portion of the Tri-State District produced more than 2.9 million tons of zinc and 650 thousand tons of lead, with a total value of $527 million. However, by the 1950's, the mining boom in the Tri-State District was basically over. The most obvious remains of the intense mining activity are large areas covered by mine wastes, water-filled subsidence craters, and open shafts. The surface mine wastes consist of bullrock, dump material, and chat. Bullrock and dump material are mainly coarse rocks and uneconomic ore removed from the shafts and mine workings to access the economic ore materials. Chat is somewhat finer in nature and is the tailing material remaining after the ore was ground and concentrated to remove valuable metal sulfides. Little or no vegetation exists in areas covered by these mining wastes.

Contamination consists of heavy metals in the mining-related waste materials covering the area and in both surface and subsurface waters flowing under, through, and into the contaminated wastes. Of particular concern to the EPA is the excess of lead minerals in the fine surface materials with the potential for ingestion by humans.

The EPA declared the Cherokee County portion of the Tri-State District to be a Superfund Site and, in 1985, began remedial action investigations. The Site was divided into six subsites and the Galena subsite was the first addressed in remedial investigations. The EPA determined that both the surface water and shallow ground water in the Galena subsite are contaminated with heavy metals and immediately instituted a program to provide treated water systems to rural consumers.

In 1988, the EPA offered a proposed plan for remediating the contaminated surface and ground waters of the Galena subsite. In general terms, this plan includes:

1. Selective placement of surface mine wastes below grade to fill the majority of pits, shafts, and depressions.
2. Channeling selected streams and drainage areas through the contaminated subsite to prevent inflow and further contamination of these waters.
3. Recontouring and revegetating the ground surface to stabilize against erosion.
4. Remediation of subsite deep wells to protect the integrity of the deep aquifer.

Today, the EPA is installing a safe drinking water system for rural Galena, and developing final remedial action plans for subsite cleanup and restoration. The Bureau is developing effective revegetation technologies for the Superfund Site to assist EPA and other interested organizations in reducing or eliminating the contamination and returning this area to some secondary land use.

METHODS

The study sites are in the southeastern corner of Kansas and are located within the city limits of Galena, Kansas. The chat tailing material and undisturbed soils utilized in this study are adjacent to each other. The undisturbed native soil (Nixa series) is a moderately well drained cherty silt loam formed in cherty limestone residuum. This soil is best suited to native range, tame grass pasture, and hay, while the chat tailings material has not been described other than as a dump (Soil Survey Staff, 1985). Typically, the piles of chat and rock cover large areas and do not support any type of vegetation.

The climate of Cherokee County is typical continental characterized by large daily and annual variations in temperature. Based on the 30-year record, 1941 to 1970, the average winter temperature is 2.8 ^{o}C with an average daily winter minimum temperature of -3.0 ^{o}C. Outbreaks of polar air are not uncommon during the winter months. The average summer temperature is 25.4 ^{o}C with an average daily summer maximum of 31.8 ^{o}C (Soil Survey Staff, 1985).

Total annual precipitation, based on the same recorded period, is 102.9 cm with 69 percent, or 71.0 cm, falling between April and September. Prolonged dry periods of several weeks are not uncommon during the growing season (Soil Survey Staff, 1985).

Study Design

The study included two experimental areas, each 105 by 60 m, utilizing a complete randomized block design. One experimental area was designated as undisturbed native soil (Nixa series), while the second area consisted of leveled chat. Within each experimental area there were seven replications of each plant species tested. Each replication was 15 by 60 m. Thirty 3 by 6 m plots were present in each of the replications; included were two control plots, 15 grass species trial plots, and 13 forb species trial plots. Two-hundred and ten plots, each 3 by 6 m, were installed in each experimental area.

The fertilizer and lime applications were based on the soil test results for each of the experimental areas (table 1). Fertilizer recommendations for both experimental areas were made by the Cherokee County Extension Agriculture Agent as actual amounts of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O). The amount of fertilizer applied to each experimental area was based on the minimum rate necessary for the establishment of new plantings of fescue, fescue-legume, and native grass (table 2). The total amount of N-P-K fertilizer applied to the native soil was 355 kg ha^{-1}, of which 146 kg was 18-46-0, 41 kg was 46-0-0, and 168 kg was 0-0-60. The total amount of N-P-K fertilizer applied to the chat tailings was 422 kg ha^{-1}, of which 195 kg was 18-46-0, 21 kg was 46-0-0, and 206 kg was 0-0-60.

Table 1. Soil test results of the native soil and chat tailings material.

	Soil pH	Organic Matter %	Available P kg ha^{-1}	Available K kg ha^{-1}
Native Soil	5.7	2.8	21.3	122.1
Chat Tailings	6.4	1.5	5.6	87.4

Table 2. Fertilizer (actual amount kg ha^{-1}) and lime (effective calcium carbonate kg ha^{-1}) recommendations.

	ECC[1] Needed	Nitrogen N	Phosphorus (P_2O_5)	Potassium (K_2O)
Native Soil	8400	44.8	67.2	100.8
Chat Tailings	1680	44.8	89.6	123.2

[1] ECC = effective calcium carbonate

The lime recommendation for each of the experimental areas (table 2) is in kg ha^{-1} of effective calcium carbonate. The actual amount of agricultural lime applied was 12,923 kg ha^{-1} and 2585 kg ha^{-1} to the undisturbed native soil and chat tailings material, respectively. Both the lime and fertilizer were broadcasted.

Species Used

Table 3 contains a complete list of the species selected for study and the seeding rates used. The species selected for study and the rates of application chosen were based on the Kansas standards and specifications for critical area planting. The purpose of the standards and specifications are to stabilize the soil, reduce damage from sediment and runoff to downstream areas, create and enhance wildlife habitat, and improve visual resources (Soil Conservation Service, 1987). These standards and specifications are applicable to highly erodible or critically eroding areas that cannot be stabilized by ordinary conservation treatment and management. Areas where the standards and specifications are applicable include dams, dikes, mine spoil, levees, cuts, fills, outlets, surface-mined areas, and denuded or gullied areas where vegetation is difficult to establish by usual planting methods.

Table 3. Species selected for study and the seeding rates used on the native soil and chat tailings material in Galena, KS.

Species	Origin[1]	Seeding Rates	
		lb. acre^{-1}	kg ha^{-1}
Cool Season Grasses			
orchardgrass (Dactylis glomerata)	I	15	16.80
smooth brome (Bromus inermis)	I	25	28.00
tall fescue (Festuca arundinacea)	I	30	33.60
tall wheatgrass (Agropyron elongatum)	I	25	28.00
western wheatgrass (Agropyron smithii)	N	20	22.40
Warm Season Grasses			
big bluestem (Andropogon gerardi)	N	15	16.80
little bluestem (Schizachyrium scoparium)	N	15	16.80
Indiangrass (Sorghastrum nutans)	N	12	13.44
sand bluestem (Andropogon hallii)	N	12	13.44
sand lovegrass (Eragrostis trichodes)	N	10	11.20
switchgrass (Panicum virgatum)	N	12	13.44
sideoats grama (Bouteloua curtipendula)	N	12	13.44
blue grama (Bouteloua gracilis)	N	4	4.48
buffalograss (Buchloe dactyloides)	N	20	22.40
alkali sacaton (Sporobolus airoides)	N	2	2.24
Non-Leguminous Forbs			
Maximilian sunflower (Helianthus maximiliani)	N	4	4.48
thickspike gayfeather (Liatris pycnostachya)	N	3	3.36
prairie coneflower (Ratibida columnifera)	N	3	3.36
Leguminous Forbs			
alfalfa (Medicago sativa)	I	18	20.16
birdsfoot trefoil (Lotus corniculatus)	I	12	13.44
crownvetch (Coronilla varia)	I	20	22.40
red clover (Trifolium pratense)	I	12	13.44
yellow sweetclover (Melilotus officinalis)	I	15	16.80
prostrate lespedeza (Lespedeza daurica var. schimadai)	I	20	22.40
purple prairie clover (Petalostemum purpureum)	N	3	3.36
Illinois bundleflower (Desmanthus illinoensis)	N	5	5.60
leadplant (Amorpha canescens)	N	3	3.36
partridge pea (Cassia fasciculata)	N	30	33.60

[1] I = introduced, N = native

All seeding rates were based on kilograms of pure live seed (PLS) per hectare; which is the percentage germination plus hard seed, multiplied by purity, and divided by 100. The actual seeding rates for each species were chosen based on the minimum PLS (kg ha^{-1}) for critical planting areas in

Kansas. Most of the species were obtained through the Soil Conservation Service Plant Materials Center located in Manhattan, KS. If the seed was not available through the Plant Material Center, it was purchased locally. All seed met the requirements of the Kansas State Seed Law which specifies the kind and amount of weed seed permitted; the requirement for a current analysis report; and, labeling of all seed to show its purity, germination, date of last germination test, and weed seed content.

Field Application

All study plots were installed and seeding accomplished during the last week of April, 1989. Site preparation of both experimental areas prior to planting included the back filling of small depressions in the surface, rock raking to remove large rock fragments, and disking to prepare the seedbed. Following fertilizer and lime applications, each species was seeded to a randomly selected plot within each replication. Each seeded plot was then hand raked to pack the seed into the seedbed.

Data Collection and Analysis

During the 1989 growing season each plot within an experimental area was surveyed for seedling emergence of planted species and the identification of volunteer plant species. Vegetation surveys were conducted in early June, August, and October. The presence or absence of seeded vegetation or volunteer species was noted at those times. No attempt was made to determine species composition in terms of species abundance, density, diversity, dominance, or richness of the seeded or volunteer vegetation during the initial growing season.

During the June sampling period, soil and chat samples were collected from each control plot within a replication for chemical characterization. Three random soil cores to a depth of 10 cm were extracted from each control plot and composite samples were analyzed on a plot basis. The soil and chat samples were submitted to the Department of Soil Science Research Analytical Laboratory, University of Minnesota for chemical analysis. The chemical characteristics of the undisturbed native soil and chat tailings material are summarized in Table 4.

Table 4. Summary of the soil chemical characteristics of the experimental areas.

Experimental Area	pH	Tot N (%)	P	K	Ca	Mg	Al	Fe	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd
			ppm													
Soil	6.3	0.1	137	153	10986	1385	886	1119	100	3946	58	2	997	7	1	18
Chat Waste	6.7	0.7	63	120	6611	2291	621	1208	59	11850	224	3	772	7	2	27

RESULTS AND DISCUSSION

Preexisting seeds in the seed bank of the native undisturbed soil had an effect on the emergence of seeded vegetation. The quantity and quality of seed banks are influenced by several factors including soil characteristics and disturbances to the soil surface. Bazzaz (1970, 1979) found that disrupting the soil surface breaks seed dormancy by exposing seeds to unfiltered light, fluctuating temperatures, and reduced CO_2 concentrations. Apparently the disking caused enough disruption of the soil surface to break seed dormancy and fertilization the nutrients necessary for growth such that total plant coverage on the undisturbed native soil increased from approximately 60 percent prior to the establishment of this study to 95 percent during the August sampling period.

As a result of the high coverage by the volunteer vegetation, the emergence of seeded vegetation was poor on this experimental area due to competition for light, nutrients, and water. Only on the areas where there was chat present did the seeded vegetation emerge. Species which emerged on the barren chat areas included smooth brome, tall fescue, orchardgrass, western wheatgrass, blue grama, sideoats grama, little bluestem, big bluestem, sand bluestem, Indiangrass, sand lovegrass, Illinois bundleflower, alfalfa, birdsfoot trefoil, red clover, yellow sweetclover, and partridge pea.

Vegetation composition of the undisturbed native soil experimental area also changed as a result of disking and fertilization. Prior to site preparation treatments and soil amendment additions, the site was dominated by switchgrass, johnsongrass (Sorghum halepense), and broomsedge (Andropogon virginicus). Surface treatments and additions of lime and fertilizer altered the species composition of the undisturbed native soil. Species which are now present on the undisturbed native soil are shown in Table 5. Site preparation and soil amendment applications resulted in a diverse plant community composed of introduced or native species and early or late successional species. Plant invasion, establishment, and composition will be monitored since these are key elements to the initial plant community (Ogle and Redente, 1988).

The plants which colonize the site are important to the types of plant communities which may develop on the site. A productive and diverse vegetative community may develop by natural processes on the chat following an initial surface disturbance by disking and fertilizer addition, but this has yet to be determined and will need continued monitoring in the coming years. Plant community development (above- and belowground productivity and species compositional measurements) and soil chemical, physical, and biological relationships within the developing plant community will be studied on the undisturbed soil and chat tailing material.

Table 5. Species composition (presence) on the undisturbed native soil experimental area.

Species	Life History[1]
Grasses	
stinkgrass (Eragrostis cilianensis)	A
little barely (Hordeum pusillum)	A
Kentucky bluegrass (Poa pratensis)	P
johnsongrass (Sorghum halepense)	P
broomsedge (Andropogon virginicus)	P
redtop (Agrostis alba)	P
switchgrass (Panicum virgatum)	P
little bluestem (Schizachyrium scoparium)	P
big bluestem (Andropogon gerardi)	P
Forbs	
moth mullen (Verbascum blattaria)	B
water hemp (Acnida altissima)	A
common ragweed (Ambrosia artemisiifolia)	A
rough pigweed (Amaranthus retroflexus)	A
tickseed sunflower (Bidens aristosa)	A
horseweed (Erigeron canadensis)	A
daisy fleabane (Erigeron strigosus)	A
common smartweed (Polygonum pensylvanicum)	A
white heath aster (Aster pilosus)	P
trumpet creeper (Campsis radicans)	P
field goldenrod (Solidago nemoralis)	P
stiff-leaved goldenrod (Solidago rigida)	P
hoary vervain (Verbena stricta)	P
Shrubs	
smooth sumac (Rhus glabra)	P
Trees	
mimosa (Albizzia julibrissin)	P
catalpa (Catalpa speciosa)	P
cottonwood (Populus deltoides)	P
black cherry (Prunus serotina)	P
sassafras (Sassafras albidum)	P

[1] A = annual, B = biennial, P = perennial

The species which emerged following seeding on the chat tailings material are shown in Table 6. The chat tailing replications and plots were surveyed twice for a total of 14 observations for each of the test species. The grass species which appeared most often were the cool season grasses, tall fescue (introduced) and western wheatgrass (native), and the native, warm season grasses, with the exception of alkali sacaton and buffalograss. Crownvetch, alfalfa, Illinois bundleflower, partridge pea (all leguminous forbs), and Maximillian sunflower (non-leguminous forb) were most prevalent of the forbs.

Table 6. Species which were seeded and emerged on the chat tailing material (based on 14 observations).

Species	Origin[1]	Number of Species Appeared
Cool Season Grasses		
orchardgrass	I	3
smooth brome	I	4
tall fescue	I	9
tall wheatgrass	I	3
western wheatgrass	N	6
Warm Season Grasses		
big bluestem	N	10
little bluestem	N	11
Indiangrass	N	4
sand bluestem	N	10
sand lovegrass	N	9
switchgrass	N	9
sideoats grama	N	10
blue grama	N	9
Non-Leguminous Forbs		
Maximillian sunflower	N	5
prairie coneflower	N	3
Leguminous Forbs		
alfalfa	I	10
crownvetch	I	10
red clover	I	3
yellow sweetclover	I	3
purple prairie clover	N	2
Illinois bundleflower	N	6
partridge pea	N	9

[1] I = introduced, N = native

Prior to site preparation, lime application, and fertilization, the chat tailings material was barren with little vegetative cover. Surface disturbance by disking and fertility treatments resulted in breaking the dormancy of the native seed bank and the invasion by volunteer vegetation as well as the emergence of the seeded test species. Volunteer vegetation on the chat material is presented in Table 7.

Table 7. Volunteer vegetation identified on the chat tailings material

Species	Life History[1]
Grasses	
stinkgrass (Eragrostis cilianensis)	A
johnsongrass (Sorghum halepense)	P
broomsedge (Andropogon virginicus)	P
switchgrass (Panicum virgatum)	P
big bluestem (Andropogon gerardi)	P
Forbs	
common ragweed (Ambrosia artemisiifolia)	A
rough pigweed (Amaranthus retroflexus)	A
tickseed sunflower (Bidens aristosa)	A
lamb's quarter (Chenopodium album)	A
horseweed (Erigeron canadensis)	A
white heath aster (Aster pilosus)	P
white snakeroot (Eupatorium rugosum)	P
gayfeather (Liatris sp.)	P
ironweed (Vernonia missurica)	P

[1] A = annual, P = perennial

The results of the vegetative survey of both seeded and volunteer species indicate that, in general, the native warm season grasses and leguminous forbs (both introduced and native) performed the best in terms of emergence and persistence on both the native undisturbed soil and chat tailings material. Native adapted species appear to be hardy enough to emerge and persist on the chat tailings material. Tall fescue, an introduced cool season grass, was the exception. Future revegetation research on the chat tailings material will include the testing of various seed mixtures utilizing those species which performed best, particularly the native species, in this initial species trial study. Additionally, the species trial plots will continue to be monitored for changes in plant productivity, species composition, and soil physical, chemical, and biological characteristics.

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Planning, Rehabilitation and Treatment of Disturbed Lands
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REINVASION OF SMALL MAMMALS, REPTILES, AMPHIBIANS AND INSECTS ON A RECLAIMED COAL STRIP-MINE

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ABSTRACT

We conducted wildlife and vegetation sampling on sites reclaimed in 1979, 1982, and 1986, as well as unmined sites, on The Pittsburg & Midway (P&M) Coal Mining Co.'s McKinley Mine in McKinley County, New Mexico. In June, July, and August 1988 and 1989 we sampled small mammals, reptiles, amphibians and insects. Soil and vegetation sampling was conducted in July and September 1988, respectively. We found several significant differences ($P < 0.05$) among plant and animal data that may have suggested differences between study sites. Recent reclamation procedures conducted or proposed by P&M promise increased wildlife value of reclaimed sites.

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P&M has been mining and reclaiming the McKinley Coal Mine since the late 1960's but has been reclaiming more intensively since the passage of state and federal mining laws in 1972 and 1977, respectively. The primary goal of the McKinley Mine's, regulatorily approved, revegetation plan is to return the land to its original use as grazing land. The revegetation program is geared to provide the forage and cover necessary to make reclaimed areas productive for grazing and erosionally stable while enhancing wildlife habitat where possible. In 1972 P&M and the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station in Albuquerque, NM entered into a cooperative agreement to study reclamation of mining spoils (Aldon and Springfield 1977). As an extension of this agreement, we investigated wildlife reinvasion on sites with topsoil replacement reclaimed in 3 different years and compared them to each other and unmined sites. From our results we hope to determine if a more diverse plant community on reclaimed sites enhances wildlife reinvasion. Unmined sites also are referred to as control sites and reclaimed sites are referred to as treatments.

Acknowledgements

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STUDY AREA

The McKinley Mine, consisting of lands either owned or leased by P&M, is located approximately 30km northwest of Gallup, New Mexico and 4km east of Window Rock, Arizona in McKinley County, New Mexico. The coal mine is at 2072m elevation with large rolling hills. The unmined sites have rocky bluffs and outcroppings. The climate is semi-arid receiving an average of 250mm of precipitation a year. Temperatures range from -37^{0}C to 38^{0}C (Aldon and Springfield 1977). In 1988 approximately 26mm of rainfall was recorded between May and August on the mine. The summer of 1989 proved to be drier with 11mm of rain recorded. May-August 1989 also was hotter with an average temperature of 19^{0}C versus 17^{0}C in 1988.

METHODS

The study consisted of twelve 120m X 120m plots. Three plots each were located on sites reclaimed in 1979, 1982, and 1986. The 3 other plots, located on unmined sites, served as controls. All plots were within 5km of each other. Sagebrush (*Artemisia tridentata*), scattered pinyon pine (*Pinus edulis*), and juniper (*Juniperus monosperma*) were native species occurring on the unmined sites. In recent years P&M, in cooperation with state and federal regulatory authorities, has been revising its seed mix to include a greater variety of native species (Table 1).

Table 1. Species seeded on reclaimed sites and percent live seed/acre (P&M, pers. commun.).

	Year seeded		
	1979	1982	1986
Species	%P.L.S./a	%P.L.S./a	%P.L.S./a
Forbs			
Achillea millefolium			0.5
Eriogonum umbellatum			0.5
Gaillardia aristata			0.5
Linum lewisii			1.0
Medicago sativa			0.7
Penstomen strictus			3.0
Rudbeckia hirta			0.5
Sphaeralcea parvifolia			3.0
Grasses			
Agropyron crystatum		16.20	
A. dasystachyum	11.54		10.5
A. intermedium		9.68	
A. riparium	21.43		
A. smithii	26.38	17.38	13.0
A. trichophorum		10.75	
Bouteloua curtipendula	20.61	9.68	5.0
Bromus marginatus			5.0
Festuca arizonica			5.0
Hilaria jamesii		2.69	5.0
Muhlenbergia wrightii			5.5
Oryzopsis hymenoides	3.30	3.71	10.0
Poa sandbergii			5.5
Sporobolus airoides			5.5
S. cryptandrus	0.25		
Shrubs			
Atriplex canescens	16.49	25.76	7.0
A. confertifolia			6.3
Eurotia lanata		4.15	7.0

Small Mammal Sampling

Small mammals were caught using Sherman live traps baited with peanut butter, rolled oats, and dimethylphthalate as described by Anderson and Ohmart (1977). Dimethylphthalate served as an ant repellent. Traps were set in 12 X 12 grids, 10m apart, on each of the 12 plots. Four plots were trapped simultaneously; 3 reclaimed plots of the same year and 1 control plot. All 12 plots were trapped for 5 days each month in June, July, and August 1988 and 1989. Trapped mammals were marked with numbered ear tags for mark-recapture data. Small mammal density was calculated using the computer program CAPTURE (White et al. 1982).

Reptile and Amphibian Sampling

Reptiles and amphibians were sampled using pitfall traps. Traps consisted of two, 1.4kg coffee cans taped end to end and put in an excavated hole. Three 7.62m steel drift fences, 46-61cm high, radiated out from a central trap at 120^0 angles with traps at each end for a total of 4 traps per array (Jones 1981). There were 3 arrays per plot. Square wooden covers, approximately 20cm X 20cm, were supported 1-2cm above the outer traps. A piece of styrofoam, approximately the same size as the wooden covers, was inserted on the edge of the 3 fences converging at the central trap. The traps were opened for 3 days each month in 1988.

Due to the low number of herps captured in 1988 all the pitfalls were left open from 1 June to 14 August 1989. Most of the styrofoam covers did not last the 9 months between summers, and no attempt was made to replace them. Some of the wooden covers were replaced by nailing 3 single covers together; 1 with its edges on top of the other 2, providing a stabler cover supported about 1cm above the trap. Neither the lack of central styrofoam covers nor the "improved" wooden covers appeared to have any effect in which traps herps were captured. In 1988 the herp arrays were checked each of the 3 mornings while checking mammal traps. In 1989 the arrays were checked every 3 to 7 days. Captured herps were marked by toe clipping.

Arthropod Sampling

There were 3 methods employed for sampling arthropods. One method used 25 pitfall traps per plot consisting of 0.45kg, 0.33kg, and 0.28kg cans (Sieg et al. 1987). There were 10, 8, and 7 of each of these cans on each plot, respectively. The cans were placed in 5 X 5 grids 20m apart. No preservative (ethylene glycol) was used in 1988. In 1989 four, 3mm diameter, holes were drilled in the sides of the cans approximately 1/4 the length of the can below the top. The holes allowed water drainage while the heavier ethylene glycol remained at the bottom (Dr. Richman, NMSU, pers. commun.).

A second method employed a sweep net (Hawkins and Cross 1982). The 30.5cm diameter sweep net was swept over the top of vegetation every meter on a randomly selected transect. The transect was 50m long and swept up and back every meter for a total of 100 sweeps (Dr. W. Whitford NMSU, pers. commun.). The sweeps were approximately 2m wide.

A third method used a portable, gas powered, model 1-A, backpack, D-vac (Deitrick et al. 1960, Johansen 1981). A randomly selected 100m transect was vacuumed with a 30.5cm diameter collecting net on each plot. The collecting end of the hose was moved across the top of the vegetation or slightly above the ground over bare soil. D-vac and sweep net methods were used at the end of each month. The pitfalls were left open all summer and arthropods collected at the end of each month.

Vegetation and Soil Sampling

Vegetation sampling was conducted in September 1988. A variation of the Community Structure Analysis (Pase 1980) was used to estimate plant cover, density, and frequency as well as litter, rock, and bare soil. Importance values for each species of plant and plant species composition values were calculated from this data. Importance values indicate vegetational dominance and are from a total possible score of 3.000 (1 point each from % cover, density, and frequency). Crown cover was estimated by collecting data from 100, 10cm X 20cm, microplots on each of 5 randomly chosen transect lines on each plot. At every tenth microplot a m^2 circular plot was used to estimate density and frequency.

Four soil samples were taken on each plot in July 1988. A 10cm diameter by 15cm deep sample was taken in the middle of each quarter of a plot. The pH, nitrogen and phosphorus content, percent sand, silt, and clay, and texture were analyzed for each sample.

Statistics

Pooled t-tests with significance at $P < 0.05$, and with the assumption of equal variances, were used to test for differences of Peromyscus spp. densities, arthropod biomass and diversity as well as vegetational and soil differences. To eliminate the problems of mice crossing over plot boundaries and population fluctuation over time, Peromyscus spp. densities were estimated by combining all 3 plots and calculating 5 day, monthly, estimates. Other statistics were calculated by combining means from the 3 plots over the 3 month sampling period. The Shannon-Weaver diversity index (Hair 1980) was calculated for all wildlife groups except the arthropods as individuals were not counted. Plant species composition was calculated by computer using a formula similar to the Shannon-Weiner index (MacArthur and MacArthur 1961).

RESULTS

Small Mammals

Four species of Peromyscus were caught and these were lumped together when calculating densities (Table 2). The 3 plots on each study site were lumped together due to mice crossing over plot boundaries on reclaimed sites. Three monthly density estimates were calculated from the 5 day trapping periods and the means compared. As Peromyscus was the only genus of small mammal captured on all the study sites it was the only genus that could be statistically compared. In 1988 the 1986 treatment and the unmined sites were found to have a significantly higher density than the 1979 and 1982 treatments. In 1989 the unmined sites had a significantly higher density of small mammals than the 1979 treatments.

Table 2. Mean Peromyscus spp. densities (mice/ha).

	1988		1989	
Treatment	$\bar{X}$	SE	$\bar{X}$	SE
1979	12.44	4.56	12.66	1.05
1982	10.46	4.75	22.74	10.64
1986	41.93	17.45	19.93	9.96
Control	51.15	21.82	26.74	6.28

All species caught or seen (Table 3) were used for diversity index calculations. The number of desert cottontails (Sylvilagus auduboni) and black-tailed jackrabbits (Lepus californicus) was estimated on plots that they were sighted on but not captured. The estimation was based on the number of rabbits or hares seen when checking small mammal traps on the respective plots. There was an estimated 10 rabbits on the control plots both years. For the hares, the estimation was 2 for both sites in 1988 and 3 for the controls in 1989. Since it was necessary to lump the plots together only one diversity index value could be derived and no statistical calculations could be done. The unmined sites appeared to have a greater diversity (Table 4). Of the more frequently captured species, cliff chipmunks (Eutamias dorsalis), woodrats (Neotoma spp.), and all but 1 pinyon mouse (Peromyscus truei), were not captured on reclaimed sites.

Reptiles and Amphibians

The captures per 100 trap-nights of tiger salamanders (Ambystoma tigrinum) and New Mexico spadefoot toads (Scaphiopus multiplicatus) in 1988 was 5-40X higher than in 1989 (Table 5). This may have be due to a wetter summer in 1988. Short-horned lizards (Phrynosoma douglassi) were most abundant (by

Table 3. Numbers of individual small mammals captured on reclaimed and unmined sites.

Species	1988				1989			
	1979	1982	1986	Un	1979	1982	1986	Un
Eutamias dorsalis				33				7
Lepus californicus[1]		X		X				X
Mus musculus						1		
Neotoma albigula								5
Neotoma mexicana				21				2
Notiosorex crawfordi[2]	1					1	1	2
Onychomys leucogaster				1				2
Perognathus apache							1	
Peromyscus boylii		1		11		1		4
P. difficilis				3				1
P. maniculatus	124	87	235	285	107	137	128	159
P. truei		1		22				1
Sylvilagus auduboni	7	1		X	12	2		X

[1] X= present but not captured.

[2] Desert shrews were captured in herp pitfall traps.

observation) on the 1979 treatment but none were captured there either year. The 4 short-horned lizards captured in 1989 were all immature and apparently not as adept at avoiding pitfall traps as older lizards.

In 1989 1 immature eastern fence lizard (*Sceloporus undulatus*) was seen on the 1986 treatment as well as the 1982 treatment, but they were probably dispersing to other areas as none were captured or seen after the first sightings in early June. Wandering garter snakes (*Thamnophis elegans vagrans*) were sighted both years only on the 1979 treatment. Two prairie rattlesnakes (*Crotalus viridis*) were seen on the 1979

Table 4. Shannon-Weaver diversity index values for herps, and small mammals.

	Year of sample	Treatment			
		1979	1982	1986	controls
Herps	1988	0.0	0.5899	0.0	0.4964
	1989	0.8783	0.9524	0.3620	1.0091
Mammals	1988	0.2897	0.2835	0.0	1.0322
	1989	0.4122	0.1993	0.0901	0.8717

treatment in 1988. A prairie rattlesnake also was seen on an unmined site in 1989.

Herp diversity (Table 4) in 1988 was probably misrepresented due to the low number of trap-nights. We believe the 1989 data is more accurate; however, only captured herps could be included in the calculations. By not capturing some species, especially adult short-horned lizards, the diversity values may be lower than they should be.

Table 5. Reptile and amphibian captures/100 trap-nights.

Species	1988[1]			1989[2]			
	1982	1986	Un	1979	1982	1986	Un
Ambystoma tigrinum	3.4	0.9			0.08	0.08	0.04
Cnemidophorus velox							0.15
Phrynosoma douglassi					0.11		0.04
Scaphiopus multiplicatus	2.2		2.4	0.08	0.08	0.46	0.46
Sceloporus undulatus			0.8	0.19			0.72
Thamnophis elegans				0.08			

[1] Total of 252 trap-nights on the unmined sites, 324 on the 1982 treatment, and 216 on 1979 and 1986 treatments.

[2] Total of 2628 trap-nights on all sites.

Arthropods

In 1988 there were 130 different species of arthropods captured from 61 families and 10 orders. The 1982 treatment had a significantly higher diversity of arthropods than all the other sites and the 1986 treatment was more diverse than the 1979 treatment (Table 6). In 1989 there were 472 species captured from at least 81 families and 15 orders. Of the 472 species 344 were not captured in 1988. The number of species captured on the 1982 treatment was significantly higher than on the 1979 treatment. Means slightly favored the highest number of species on the unmined sites. Arthropod biomass, obtained only from pitfall samples, was significantly higher on the 1979 treatment than unmined sites in 1988 (Table 6). In 1989 biomass was higher on the 1986 treatment than on all other sites. Differences from year to year in species and biomass was probably a result of heavy rains washing out pitfalls in 1988 and the addition of ethylene glycol to pitfalls in 1989.

Vegetation Characteristics

Mean percent cover was statistically higher on the 1979 treatment than the unmined sites. Plant species composition was statistically higher on the unmined sites than reclaimed sites (Table 7). Streambank wheatgrass (*Agropyron riparium*)

Table 6. Mean arthropod species and pitfall biomass.

	Species				Biomass (g/M^2)			
	1988		1989		1988[1]		1989	
Treatment	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
1979	28	0.58	57	5.51	165	37.40	239	87.43
1982	44	1.53	80	12.58	123	43.89	295	75.02
1986	38	1.00	102	7.00	367	234.04	979	154.38
Control	33	3.79	103	47.12	86	30.82	300	230.72

[1] Mean biomass in 1988 does not include June because only the 1982 treatment and control 1 were sampled that month.

had a mean importance value (IV) of 2.088 ± 0.068 on the 1979 treatment. The other 13 species occurring on the 1979 treatment all had IV's of 0.460 or less. Pubescent wheatgrass (*A. trichophorum*) was most dominant on the 1982 treatment with a mean IV of 1.881 ± 0.357. The other 10 species of plants had IV's of 0.666 or less. The two dominant plants on the 1986 treatment were annual forbs. One was Russian thistle (*Salsola kali*) with a mean IV of 1.285 ± 0.137 and the other was summer cypress (*Kochia scoparia*) with a mean IV of 1.232 ± 0.280. The other 31 species had IV's of 0.148 or less. Forty-nine species of plants occurred on the unmined sites. Western wheatgrass (*Agropyron smithii*) was the most dominant grass with a mean IV of 0.523 ± 0.067, broom snakeweed (*Gutierrezia sarothrae*) was the most dominant forb with a mean IV of 0.402 ± 0.112, and sagebrush was the most dominant shrub with an IV of 0.431 ± 0.129.

Table 7. Mean plant diversity and cover values.

	Diversity		% Cover	
Treatment	$\bar{X}$	SE	$\bar{X}$	SE
1979	0.66	0.07	50.6	1.76
1982	0.77	0.31	38.7	6.51
1986	0.84	0.12	48.8	7.28
Control	2.06	0.21	40.5	2.52

Soil Characteristics

The 1986 treatment’s mean pH was 7.72, the 1982 treatment’s was 7.63, and both the 1979 treatment’s and unmined site’s mean pH were 7.50. Electrical conductivity, percent organic matter, and nitrogen and phosphorus content were the same on all sites. There was no statistical difference among pH nor was there any statistical differences between sand, silt, and clay contents.

DISCUSSION

Small Mammals

Baker and Frischknecht (1973) studied areas in Utah after chain removal of juniper and subsequent reseeding. Deer mice had the highest abundance 2 years after clearing. However, the populations on the cleared areas dropped 3-7X the third year. The deer mouse density on our 1986 treatment was twice as high in 1988 as in 1989 so in this respect our results are similar to theirs.

A previous study on the McKinley Mine showed a higher number of deer mice per 100 trap-nights on the 3 year old reclaimed sites than unmined sites (Steele and Grant, Bio-Resources, unpubl. data). When we examined deer mice only, our results showed a higher mean number on unmined sites but there was no statistical difference.

Hoag et al. (1982), working in Montana and Wyoming, and Quayle (1985), in northeastern Wyoming, found more species of small mammals on unmined sites (10 and 7, respectively) than reclaimed sites (6 and 3, respectively). Hingtgen and Clark (1984) however, found 8 species occupying 3-5 year old reclaimed sites, 6 species on 2 year old sites and only 5 species on unmined sites on a coal mine located in northeastern Wyoming. Our results were more similar to Hoag et al. (1982) and Quayle’s (1985) studies with respect to species. Over both sampling years we found 11 species on unmined sites, 3 species on the 1979 treatment, 7 species on the 1982 treatment, and 3 species on the 1986 treatment.

Reptiles and Amphibians

Stebbins (1985) indicated that the plateau striped whiptail only occurs in areas with trees. Our findings support this, and they also support Stebbins by other herps being captured in a wide range of habitats (Table 5). Diversity indices were calculated using captured species only. If observed species are added there were 6 species on the controls with the addition of the prairie rattlesnake, 5 species on the 1979 treatment adding short-horned lizards and prairie rattlesnake, 4 species on the 1982 treatment with the addition of the eastern fence lizard, and 3 species on the 1986 treatment also adding the eastern fence lizard.

Arthropods

By examining the mean number of species captured in 1989, a trend of lower diversity on older reclaimed sites is apparent (Table 6). Parmenter and MacMahon (1987), working in southwestern Wyoming, found an increase in species diversity the first 3 years after reclamation but a decline after 3 years. Insect biomass might be greatest on our 1986 treatment because of high plant litter from invading Russian thistle and straw mulch accumulation in trenches. No other vegetation or soil data explains our biomass differences.

Vegetation and Topography

Tessman (1982) suggested leaving or creating various structures or features for reclamation in Wyoming. Some of these were islands of natural vegetation, rock piles, boulders, brush piles, surface depressions, undulations and gouges. We are pleased to report that the P&M Coal Mine is implementing or proposes to implement these actions in their reclamation program (P&M, pers. commun.). The 1986 treatments have surface undulations and gouges which may benefit wildlife.

MANAGEMENT IMPLICATIONS

P&M is following its reclamation plan and is reclaiming primarily for grazing purposes but some recommendations suggested by Tessman (1982) are being implemented and may benefit wildlife. Although the more diverse seed mixture on the 1986 treatment is geared towards grazing benefits, wildlife may also benefit.

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IMPACTS OF SURFACE MINING ON CALVING ELK

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ABSTRACT

Due to concern over potential impact of surface coal mining on a traditional elk calving ground, Colorado Yampa Coal Company conducted a six and one half year study from 1981 to 1987 to monitor elk calving behavior in connection habitat disturbance resulting from mining. The specific objectives were to: (1) determine if productivity of elk is changed as they are displaced from a traditional calving area; (2) determine what fidelity they exhibit to calving areas; and, (3) describe the physical and vegetational characteristics of elk calving areas. During the study, 448 elk captures were recorded, 294 individual elk were tagged, 75 of which received radio transmitters. The radio transmitter collared elk were relocated 4,583 times. Telemetry work on the 75 individual elk revealed no negative impacts on elk using the mine site. Productivity, calving home range size and fidelity, and habitat utilization patterns between elk using the mine site and control elk were not significantly different. There has been no indication that elk are abandoning mine areas. Aspen habitats directly adjacent to active mining continue to be selected for during the late spring and summer. Reclaimed sites are used in proportion to their availability during spring and summer and are selected for during the fall and early winter. In addition, a large amount of information on cow elk mortality, summer and winter ranges, migration patterns and habitat utilization was obtained.

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INTRODUCTION

In recent years there has been increasing concern for the specific habitat which cow elk utilize for calving. As a result of this concern, a portion of the coal within Colorado Yampa Coal Company's (CYCC) permit area was originally designated as unsuitable for mining. This area had been identified by various regulatory agencies as being an elk calving ground and it was felt that mining of the area would result in significant negative impacts to the elk.

Although elk were known to use this area for calving, there was insufficient data to document the exact importance or extent of this calving ground in connection with the regional productivity of the elk herd. In addition, monitoring of elk calving during 1979 and 1980 revealed that the area being used by elk for calving and suitable for calving was more extensive than originally believed. Although it was still felt that there would be negative impacts to the elk, it was also believed that these impacts could be substantially mitigated and that the situation provided an excellent opportunity to study the effects of surface coal mining on elk. Therefore, it was subsequently decided that the area could be mined, with the stipulation that CYCC conduct a five year elk study and the unsuitability designation was reversed. As a result, this study was designed and conducted.

The purpose of the study was to monitor elk calving behavior in connection with habitat disturbance resulting from surface coal mining, document the impacts, and identify what calving elk were selecting for. In order to accomplish this, three specific objectives were defined: 1) determine if productivity of elk is changed as they are displaced from a traditional calving area, 2) determine what fidelity elk exhibit to calving areas, and 3) describe the physical and vegetational characteristics of elk calving ground.

STUDY AREA

CYCC's Eckman Park Permit area of approximately 10 mi^2 (the area of intensive investigation) is located approximately 20 miles southwest of Steamboat Springs, Routt County, Colorado. However, the area of study extends as far as 20+ miles in almost all directions covering the movements of elk tagged on the mine.

The major vegetation types in the area are aspen on northerly aspects and mountain shrub on southerly aspects (major species being gambel oak, snowberry, chokecherry and serviceberry). Sagebrush, cultivated land, conifer, grassland, and mining reclaimed land account for most of the remaining vegetation types.

Elevation ranges from 6,800 to 8,400 feet on the mine site but extends up to 11,000 feet to the south in the flat tops, and down to 6,000 feet northwest of the mine. Precipitation on the mine site averages 16 inches annually.

METHODS

Elk were trapped in clover traps with alfalfa and or salt from 1981 through 1985. Clover traps were constructed and operated at CYCC following the design described by the Colorado Cooperative Wildlife Research Unit (1979) and Seitz (1980). A portable corral trap provided and operated by the Colorado Division of Wildlife was also used in 1982. Age was estimated using lower incisor tooth replacement and wear. A Telonics radio transmitter or numbered conventional polyurethane collar was placed on each adult and yearling cow elk. Calves and bulls received ear tags only.

Aerial and ground surveys were conducted to monitor and relocate animals equipped with radio transmitters and observe animals with non-telemetry, conventional markings. Fixed-wing aircraft (Cessna 182 or 206) were used once monthly, twice in May and four times in June. Ground surveys were conducted during the calving period (May 15 - June 30). Locations of tagged elk were marked on topographic maps. Habitat type and elk activity (when possible) were also recorded.

Annual helicopter surveys were conducted to obtain cow/calf ratios and determine elk productivity. In order to determine if productivity differed between elk using areas being mined and non-mined areas three large surface coal mines and five control sites were surveyed.

Elk calving home range size was determined for each radio transmitter elk using Mohr's (1947) minimum convex polygon method. Two home ranges were calculated for each elk. Observations between May 15 and June 30 were used to delineate the general calving home range. Data gathered from May 25 to June 15 was utilized to identify the refined calving home range.

Calving home range fidelity was determined by planimetering the amount of overlap between calving home ranges in consecutive years for each individual. The area of overlap was then divided by the smallest of the two overlapping home ranges to give a relative percent overlap.

As another index to calving home range fidelity, centers of activities ("arithmetic mean center" Dixon and Chapman 1980; "geometric center", VanWinkle 1975) were calculated for each calving home range. Activity centers were determined by taking the average of all the x and y coordinates for all locations within the calving home range. When more than one location was obtained on an elk in a single day, these locations were averaged and one set of coordinates for that day was used in the overall calculation for the activity center. This prevented any one day from having a disproportionate influence on the activity center location. The distance between year to year calving home range activity centers was then measured.

Analysis of variance and Duncan's multiple range test were then used to determine differences (in cow:calf ratios, home range size, relative percent overlap and distance between activity centers) between elk using mine sites and control areas. Significant levels used were $\alpha = 0.05$.

Habitat utilization was determined by calculating the percentage of locations within each vegetation type for radio transmittered elk. Habitat selection was then determined by using Chi-square analysis ($\alpha = 0.10$). Selection was defined as the statistically significant utilization of a habitat greater or less than its availability.

Available habitat was determined using two methods. One method involved determining what was available over the entire area. One thousand random points were placed over 650 mi^2 area and the vegetation type at each point determined. The other method was used to determine what was available within calving home ranges. It involved taking the average percent of each habitat type within calving home ranges for a specific group of elk.

RESULTS

One thousand seven hundred thirty-five individual clover trap nights and 6 corral trap nights yielded 448 captures. Of the 448 captures, 82 were recaptures, 44 were released untagged and 28 escaped untagged, leaving 294 individual elk which were tagged. Seventy-five of the 294 received radio transmitter, 73 conventional collars and 146 ear tags. Three hundred fifty-one of the elk which were trapped were classified (9 yearling bulls, 139 adult cows, 27 yearling cows, 176 calves). Annual trap success varied depending on season, winter conditions, and experience from 18% to 78%. Only 3 elk were injured as a result of trapping which represents less than one percent of those handled.

Ground and aerial radiotracking between January 1, 1981 and July 31, 1987 yielded 4,583 locations of the 75 radio transmittered elk. The length of time individuals were monitored with operating transmitters averaged 28 months (2.35 years) for a total of 176.4 elk years, and ranged from 4 to 72 months (.33 to 6.0 years). Two elk were monitored for 5 years or longer, and additional 10 for 4 years or longer, 11 more for 3 years or longer and 14 more for 2 years or longer. Approximately 9 transmitters failed prematurely (< 3 years old) and 4 of these operated for at least 2 years.

Compared to radio transmittered elk, conventionally collared and ear tagged elk yielded very little data and as a result it is not reported here.

The average general calving home range (May 15 to June 30) size for all elk over all years was 2.25 mi^2 (N=184) and ranged from .02 to 24.98 mi^2. The average refined calving home range (May 25 to June 15) size was 0.54 mi^2 (N-175) and ranged from 0.00 to 5.06mi^2. There was a significant degree of variability in calving home range size. Some of these differences were due to differences in age and behavior patterns of individual elk. In order to evaluate these differences and determine if there were any differences in calving home range size between elk using mine and control areas, elk were divided into four groups: 1) Yearling (elk less than two years old prior to the start of the calving period), 2) Summer Migrants (elk which move to substantially higher elevations during June or July), 3) Mine Elk (elk which calved and summered in close proximity to active surface coal mines, and 4) Control Elk (elk which calved and summered at elevations similar to mine areas).

Statistical analysis among these four groups indicated that yearlings and summer migrants had significantly larger general calving home ranges than control and mine elk. Mine and control elk were not statistically different. Only yearlings had significantly larger refined calving home ranges.

GENERAL CALVING HOME RANGE SIZE

Elk	Mean(mi^2)	N	Range (mi^2)
Yearlings	7.84	5	2.15 - 23.09
Summer Migrants	5.53	17	0.31 - 17.05
Control	2.20	76	0.02 - 24.98
Mine	1.32	86	0.01 - 15.26

REFINED CALVING HOME RANGE SIZE

Elk	Mean(mi^2)	N	Range (mi^2)
Yearlings	2.82	5	0.52 - 5.06
Summer Migrants	0.94	14	0.01 - 3.79
Control	0.41	73	0.00 - 3.86
Mine	0.44	83	0.00 - 2.23

The above statistical analyses were complicated by differences in relocation sample size (number of relocations per elk used to calculate home range size) between mine and control elk. All elk were located at weekly intervals at least 5 times during the calving period during aerial surveys. However, many elk particularly those at CYCC, where access was sufficient, were located much more often during ground surveys. On the average mine and control elk were located 16 and 8 times respectively during the calving period. Because increasing relocation sample size can increase home range size a second analysis was done. During this analysis only 5 aerial observations were used to calculate home range size for mine and control elk. Home range sizes were not significantly different between control elk ($\bar{x}$ = .80 mi^2 N=74 range 0.01 to 3.26 mi^2) and mine elk ($\bar{x}$ = .55 mi^2 N=84 range 0.02 to 4.06 mi^2).

It is apparent from the above analyses that relocation sample size was insufficient in many cases to give an accurate calving home range size. Typically, doubling the number of relocations (biweekly instead of weekly) doubled the calving home range size, provided these relocations were relatively equally spaced in time through the calving period. Additional relocation beyond this typically had a much lower impact on home range size. In addition, numerous relocation (i.e. 10) within a short period such as 24 to 48 hours had little affect on home range size. In spite of this, differences between the four groups of elk are probably valid. This is confirmed by the observation that yearlings and summer migrants were located fewer times on the average than mine and control elk. The lack of difference between mine and control elk is substantiated by the second analysis where relocation sample size was kept constant between the two groups.

In summary, the results show no significant difference between mine and control elk. However, general calving home range size for mine elk tended to be smaller. Edge et al, (1985) found a similar response due to logging disturbance.

Relative percent home range overlap for general and refined calving home ranges for all elk averaged 54% (N=113 range 0% to 100%) and 29% (N=107 range 0% to 100%) respectively. Statistical analysis indicated no significant differences between the four groups of elk for either general or refined calving home ranges. However there was a tendency for mine elk to have greater overlap.

GENERAL CALVING HOME RANGE OVERLAP

ELK	Mean (%)	N	Range (%)
Mine	65	53	0 - 100
Control	45	46	0 - 100
Summer Migrants	41	11	0 - 91
Yearlings	37	3	0 - 69

REFINED CALVING HOME RANGE OVERLAP

Elk	Mean (%)	N	Range (%)
Mine	35	50	0 - 100
Control	25	45	0 - 100
Summer Migrants	20	9	0 - 83
Yearlings	22	3	0 - 67

These results are again complicated by differences in relocation sample size which affects calving home range size as previously discussed.

Linear distance between consecutive season activity centers for calving home ranges proved to be a better method for determining differences in fidelity between the four groups of elk. Unlike home range size relocation sample size did not have a significant affect upon distance between activity centers. Weekly relocations during the calving period did provide a fairly accurate estimation of the activity center. For both general and refined calving home ranges yearlings had significantly higher distances between activity centers than all other elk. Summer migrants had significantly further distances between activity centers than control and mine elk. Control and mine elk were not significantly different.

DISTANCE BETWEEN GENERAL ACTIVITY CENTERS

Elk	Mean (mi)	N	Range (mi)
Yearlings	3.66	4	0.19 - 12.69
Summer Migrants	2.16	11	0.18 - 4.60
Control	0.75	44	0.11 - 3.26
Mine	0.42	51	0.02 - 1.14

DISTANCE BETWEEN REFINED ACTIVITY CENTERS

Elk	Mean (mi)	N	Range (mi)
Yearlings	3.48	4	0.36 - 10.63
Summer Migrants	1.98	11	0.21 - 4.39
Control	0.76	44	0.04 - 3.26
Mine	0.54	50	0.00 - 1.44

Baumannn (1985) found similar differences in fidelity to calving home ranges between resident and migrant elk although overall fidelity was not as great.

The overall mean distances between activity centers for both general and refined calving home ranges were similar, 0.84 mi (N= 110 Range 0.02-12.69 mi) and 0.88 mi (N= 109 Range 0.00-10.63 mi) respectively. The indication is that there is less fidelity to the refined calving home range than the general. This is deduced because refined home ranges are smaller than general and yet they are as far apart. This is confirmed by there being less overlap for refined calving home ranges. Both Ward (1985) and Baumann (1985) came to similar conclusions, that elk often show fidelity to some general area during calving but not to a specific area.

This data also indicates that there has been little or no displacement of elk from calving home ranges as a result of mining since the study began.

Although the data for summer and winter range fidelity was not statistically evaluated, it was apparent that fidelity to summer range was much greater than for winter range. This has been found by a number of authors (Kuck, et al, 1984; Lonner, 1979). It was also apparent that fidelity to summer range was as great or greater than to calving areas. The amount of fidelity to calving areas evidently varies a great deal in some areas. Skovlin (1982) stated there seems to be little evidence of annually repeated use of calving areas by specific cows beyond the normal happenstance of a herd being at about the same locality during migration on successive years. However, he stated there were exceptions that show habitual use of calving areas by certain cows. Kuck, et al, (1983) noted a high degree of fidelity to calving areas and concluded that traditional use of calving areas by individual cows suggests favorable conditions for calving are predictable and that fidelity to these areas develops in response to predictable conditions. Examination of Kuck's data indicates that fidelity to summer range is as great as fidelity to calving areas based on distance between activity centers and percentage of home range overlap. In many areas, elk calve during spring migration and calving habitat probably depends largely on availability. Our data seems to indicate that elk are showing fidelity to summer range rather that specific calving areas. Elk in our study which summer at lower elevations were able to reach their summer range prior to calving and showed greater fidelity to calving areas. Elk which summered at higher elevations did not reach summer range areas before calving due to snow and plant phenology and showed less fidelity to calving areas.

Helicopter surveys were conducted each year 1982-1987 during July to obtain cow:calf ratios. Approximately 500 elk per year were classified on three surface coal mines (CYCC's

Eckman Park Mine, Pittsburg Midway's Edna Mine, Seneca's Mine II) and 500 per year on comparable control areas (Middle Creek, Quarry Mountain, Thorpe Mountain) representative of our control elk. In addition approximately 375 per year were classified on two high elevation sites (Little Flat Tops, Dunckley Flat Tops) representative of summer migrant elk. Statistical analysis show no significant differences between mine and control elk. However summer migrants had significantly lower calf ratios.

CALVES PER 100 COWS

Elk	1982	1983	1984	1985	1986	1987	Over All
Mine							
$\bar{x}$	67	54	51	44	54	60	55
Range	55-81	47-60	50-52	39-58	50-64	58-60	
Control							
$\bar{x}$	56	51	48	53	54	58	53
Range	50-64	44-58	46-50	53-54	52-56	57-59	
Summer Migrants							
$\bar{x}$	35	50	38	49	53	53	46
Range	33-35	49-50	38-38	48-49	51-60	52-54	

One thousand, seven hundred and ninety nine (1,799) relocations, between May 15, and June 30, where vegetation type could be determined, were used in the calving habitat utilization and selection evaluations. For purposes of comparison elk were divided into 5 different groups. These groups are similar to those previously defined (Yearling, Summer Migrants, Mine, Control). However, the control group was divided into 2 groups (Control 1, Control 2). Control 1 elk were trapped at the same sites as mine elk and had similar habitat use and selection patterns during calving. Most of Control 2 elk were trapped at a location further from the mine site and showed some significant differences in habitat use and selection.

HABITAT UTILIZATION

Vegetation Type	% of General Region	% of Calving Home Range	% of Relocations
Summer Migrants, Mine and Control I			
Aspen	20	45	57
Mtn Shrub	25	27	26
Control II			
Aspen	20	25	29
Mtn Shrub	25	52	60
Yearlings			
Aspen	20	31	38
Mtn Shrub	25	41	42

In general calving habitat was characterized predominately by aspen and secondarily by mountain shrub. Chi-square analysis show that aspen was selected for both within the region and within the calving home range. Mountain shrub was used in proportion to its availability. Other vegetation types represented only a small portion of calving habitat and were generally used in proportion to availability within calving home range.

The exception to the above was for Control 2 elk and yearlings. Control 2 elk selected for mountain shrub within the region but within their calving home range used it in proportion to its availability. Aspen was used in proportion to its availability. Yearlings showed some selection for both aspen and mountain shrub within the region but used both in proportion to their availability within their calving home range.

Habitat utilization and selection was also determined for the entire year. Analysis of 3703 relocations over 6 1/2 years revealed the following general patterns.

During the summer (June - September) aspen was selected for (64% of all relocations) and mountain shrub was used in proportion to its availability (21% of all relocations). Grasslands, although minor portions of available habitat (6%) were also used in proportion to their availability. Late summer (August - September) is the only time when conifer was used in proportion to its availability (13%). Conifer was selected against at all other times. Other types were selected against.

During the fall (October - December), cultivated lands predominately grain fields (25% of all relocations) and reclaimed mine sites (17% of all relocations) were selected for. Mountain shrub was used in proportion to its availability. There was decreasing use of aspen and other types were selected against.

During the winter (January - March), mountain shrub was selected for (70% of all relocations). Reclaimed and cultivated sites were used in proportion to their availability at times. Other types were selected against.

During the spring (April - May) use shifted from mountain shrub to aspen. This is also the only period when sagebrush areas were used in proportion to their availability (16%).

Although not an original part of the study design some interesting information was also gathered on the causes and rates of mortality for cow elk.

		PERCENT MORTALITY				
YEAR	BEGINNING # TRANS-MITTERED ELK	LEGAL HARVEST	ILLEGAL HARVEST	CRIPPLING LOSS	WINTER MORTALITY	TOTAL MORTALITY
1981-82	20	5	5	5	5	20
1982-83	35	3	3	3	3	11
1983-84	48	6	4	2	10	23
1984-85	36	19	8	3	0	32
1985-86	29	10	0	3	0	13
1986-87	18	6	6	0	0	11
$\bar{X}$		9	4	3	4	19

As would be expected hunting was the major cause of mortality.

Legal harvest varied depending on number of cow permits given and seemed to be increased when those permits were issued during later hunts (i.e. December). There was also a large degree of loss from illegal harvest and crippling loss. Similar losses have been documented by others (Kuck 1984). Winter mortality was usually relatively low but jumped to 10% during the harsh winter of 1983-84. The majority of these winter mortalities was in older age cows.

DISCUSSION

The original Environmental Impact Statement (EIS) predicted that elk use would be reduced 100% within a quarter mile radius of mine facilities and active mining. Many of the government regulatory agencies involved originally felt that mining would cause increased movement and harassment of calving elk resulting in stress at a time when energy demands are already at their peak due to late stages of gestation, lactation and growth of calves. They felt that high quality calving areas would be abandoned and that the effect of this would be compounded by the high degree of fidelity (traditional use) which they believed individual elk exhibited for specific calving sites (Seidel 1977). As a result of all this they felt the productivity of the elk using the mine area would be reduced.

During this study none of these negative impacts could be documented. No significant differences could be found in reproduction, calving home range size, fidelity or habitat utilization and selection patterns between elk using mine and those using control sites. There has been no indication that elk are abandoning mine areas. There continues to be extensive use by elk within a 1/4 mile radius of active mining operations. In fact during the first 3 years of the study when mining was occurring in aspen habitats, approximately 20% of all calving home range activity centers for elk using the mine area were within 1/4 mile of active pits where blasting was occurring almost daily, and 70% were within 1/2 mile. Given the average home range size of 1.32 mi^2 for these elk it is obvious that there was a significant amount of use within 1/4 mile. Some of the most successful trapping sites during the study were within 1/4 mile of active pits. Later increases in distances between activity centers and active pits were not the result of elk movement but movement of mining activity away from aspen.

It is important to note that over 1,100 acres have been disturbed by mining at CYCC since the study began in January 1981; however, only 260 of these acres were covered by aspen. The relatively small amount of aspen habitat disturbed may partially explain why little or no displacement from calving home ranges was documented. It is also important to realize that some displacement has probably occurred in the past because over 4,000 acres, approximately 1,000 acres of which were aspen, have been disturbed at CYCC since mining began in the early 1960's. The Seneca and Edna mines are also large surface coal mines and have mined in similar aspen and mountain shrub habitats and yet continue to have excellent elk populations also. This would indicate that availability of calving habitat is currently not a limiting factor to this elk population.

The only impact mining in the study area appears to have is the temporary loss of aspen habitats which are actually disturbed. In this study aspen and mountain shrub were selected by elk during the calving period. As aspen habitats are changed to newly reclaimed lands, this obviously changes utilization of these areas. However, this change has had no measured adverse impacts on the elk in the study area. Mined lands are quickly reclaimed an although newly reclaimed lands provide less cover for elk, they do provide excellent forage in greater abundance than found in aspen habitats. These newly reclaimed lands, although not selected during calving are used in proportion to their availability during this period. In addition, reclaimed areas are being selected for during the fall months. This probably results from the quality and abundance of forage on reclaimed sites and the reduced thermal cover requirements of elk during this time of year.

Although population estimates were not a part of this study it was obvious that the elk populations were as high or higher on mine sites than on control sites. This was evident from cow:calf helicopter surveys where slightly larger control sites were necessary in order to classify the same number of elk. This is also recognized by the Colorado Division of Wildlife as evidenced by their desire to get increased harvest on mine sites, in spite of the fact that our study showed that elk on the mine were being harvested at the same rate as on control sites.

The results of this study are very similar to those found by Kuck (1984). There are a number of close similarities between the two studies that make them very comparable. These similarities include habitat type, home range size, fidelity, and habitat utilization and selection patterns, during the calving period. The Idaho study involved 4.5 years of extensive radio telemetry work on deer, elk and moose, as well as pellet group count data. Kuck (1984) could find no evidence that deer, elk or moose were being displaced from areas adjacent to mines. In addition, an experiment was conducted involving the direct human disturbance and simulated mine noises upon transmittered deer and newly born elk calves. The study reports that home range size and habitat utilization patterns for deer subjected to these treatments were not significantly different from control deer. However there were significant influences upon elk calves. Elk calves subjected to these treatments moved significantly greater distances and had much larger home range size than control elk. Elk calves also showed some variations in habitat utilization patterns. However, as pointed out in the Idaho study, the treatments tested resulted in human harassment much more severe than encountered during mining. In spite of the influence of these treatments on elk calves, there was no resulting increase in mortality which was monitored through the first winter. Results suggested that effects of disturbance during the calving period may be less important than other factors. It is suggested that such factors as nutritional plane of the mother may be more important.

In conclusion, our data indicates that coal mining and its associated forms of surface disturbance, at CYCC and the surrounding surface coal mines, within documented elk calving home ranges appears to have no measurable negative impact upon the local elk population.

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MITIGATION PLANNING FOR RAPTORS DURING MINING

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ABSTRACT

Birds of prey and their eggs, young and nests are protected by state and federal laws and regulations. Surface mining operations may experience conflicts with raptors when expanding into nesting areas or when raptors are attracted into mining areas. State and federal permits are required for disturbance or manipulation of birds of prey. Mitigation planning for raptors begins before mining and continues through mining. As conflict situations change, so must the mitigation plan. Before each nesting season the mining schedule should be compared to areas of known raptor nesting activity. If overlap occurs, nest protection measures may be needed. Areas of potential conflict should be patrolled regularly to identify the presence of a raptor pair and nest starts. Should a raptor nest be built and eggs laid, a change in the mining schedule or an egg or brood manipulation may resolve the conflict. Bridger Coal Company has successfully mitigated conflicts with 3 raptor species. A ferruginous hawk (Buteo regalis) nest with brood was successfully relocated across a pit. Red-tailed hawk (B. jamaicensis) egg clutches were removed from 2 highwall nests and transported in a portable incubator to a commercial raptor propagator where they were hatched, fed and conspecifically imprinted until achieving self-thermoregulation. All chicks were returned to the mine and successfully placed into foster nests. A metal artificial nest ledge for a prairie falcon (Falco mexicanus) was constructed in a cliff and a traditional nesting ledge rendered inaccessible. The falcon pair successfully nested in the artificial ledge.

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INTRODUCTION

Surface mines in Wyoming and other western states can affect habitat occupied by raptors. Mines also provide habitat that is used by many raptor species. Destruction of nest sites or disruption of nesting activities of these species are prohibited by several legislative acts. The Migratory Bird Treaty Act of 1918 (16 U.S.C. 703-711) as ammended in 1972 protects all raptors, their parts, eggs and nests. The Bald Eagle Protection Act (16 U.S.C. 668-668d) specifically protects bald (Haliaeetus leucocephalus) and golden eagles (GOEA; Aquilla chrysaetos). The Endangered Species Act (16 U.S.C. 1513-1543) gave special protection to bald eagles, peregrine falcons (Falco peregrinus) and other species. Regulations pursuant to the above statutes are 50 C.F.R. Parts 10, 17, 21, 22 and 23. State laws also protect raptors.

The Surface Mining Control and Reclamation Act of 1977 (30 U.S.C.1201) protects wildlife from activities associated with coal mining. Comprehensive wildlife baseline studies are required in mine permit applications. The federal Office of Surface Mining and State Regulatory Authority (Dept. of Env. Qual./Land Qual. Div. in Wyoming) review mine permit applications and evaluate conflicts with wildlife and other resources. A Raptor Mitigation Plan (RMP) is required which addresses each potential conflict and describes action to mitigate negative impacts. Each RMP must be approved by the U.S. Fish and Wildlife Service (FWS) and the State wildlife agency (Wyoming Game and Fish Dept. in Wyoming; WGFD) prior to issuance of a mining permit.

While activities that adversely affect raptors are prohibited or restricted by statute and regulation, provisions exist for special purposes and scientific collection. Permits from both FWS and WGFD have been issued to allow work with raptors to develop and test mitigation techniques. Techniques include nest manipulation, buffer zones, sensitivity to and timing of disturbance actions, and other innovative ideas to resolve raptor conflicts. The goal in designing and implementing mitigation was to preserve the existence of and insure the reproductive success of raptors while allowing scheduled mining operations to continue with minimal delay.

Baseline studies were conducted for Bridger Coal Company (BCC) at the Jim Bridger Mine (JBM) prior to mining. The studies predicted little impact to raptors, although the permit area was shown to support large, dense and diverse raptor populations. During 15 years of mining approximately 10 mi. of cliff-like highwalls have been created, and raptors have selected them and associated spoil piles as nesting sites on numerous occasions. These pit nesting raptors have become a source of conflict on occasion. Our objectives were to identify the procedures used at BCC in planning and implementing raptor mitigation and to present the history of and solutions used in mitigation case studies. The 3 species discussed are ferruginous hawk (FEHA; Buteo regalis), red-tailed hawk (RTHA; B. jamaicensis) and prairie falcon (PRFA; Falco mexicanus).

METHODS

Investigations were conducted at the JBM located 35 mi. northeast of Rock Springs, WY, USA. The mine was opened in 1974 and has produced 83 million tons of coal through 1989. In that time, mining has disturbed 5,200 of the 20,000 acre mine permit area. The wildlife study area is 40,000 acres. Geologically, the area is an anticlinal structure known as the

Rock Springs Uplift with surface elevations ranging from 6,500 to 7,200 ft. The topography is rolling and extensively dissected by incised ephemeral drainages. A long series of escarpments with prominant rimrock trends from north to south just west of the permit boundary. Rimrock is dominated by sandstone with lenses of shale, mudstone and coal. The climate is semiarid to arid and mean annual precipitation is 7 - 9 in. The habitat type is sagebrush-wheatgrass (*Artemisia* spp.-*Agropyron* spp.; Bailey 1978). The vegetative community is a mosaic of sagebrush-grass and saltbush (*Atriplex* spp.).

We define a *nest*, *nest site* or *eyrie* (i.e., *nest structure*) as the area in and immediately around a nest or nest scrape (i.e., sticknest and/or ledge). A single *nest territory* contains one nesting pair and, possibly, alternative nest structures. Overlap of nest territories between species occurred, overlap within species did not. A nest territory may be occupied by a single raptor or a pair. A pair that laid egg(s) made a *breeding attempt* and was considered *reproductive* (i.e., *active*). A pair that reared its nestlings until they left the nest or fledged was considered successful.

Most of the mitigation techniques used have been described by Postovit and Postovit (1987). Additional information relating to mitigation techniques include: nest manipulations with chicks (Fala et al. 1985, Postovit et al. 1982); chick fostering (Barclay 1987); egg transport and incubation (Barclay 1987); and artifical nest ledge construction (Boyce 1987, Boyce et al. 1980, Fyfe and Armbruster 1987, Runde and Anderson 1986, Smith 1985).

Mitigation planning begins before each nesting season in late winter. Locations of nesting territories that intersect pit disturbance are compared to the mine plan. Potential conflicts between scheduled mining and nesting can be prevented by deterrence or mitigated. Nest territories encompass an area where a given pair has historically nested. They are an effective functional tool for predicting where nesting attempts are likely to occur. They are not, however, the pair's biological territory or home range. Mining can create new and initially unoccupied nesting habitat and nest territories can shift from year to year. Alternative nesting opportunities were then identified (e.g., existing nests or substrates) or created (e.g., nest platforms and/or nests) when possible to insure that a pair would not be excluded from nesting.

The "conflict areas" were patrolled by an observer in a vehicle or on foot using binoculars and a spotting scope. Patrols began by February for early nesting species, such as, the GOEA and great horned owl (GHOW; *Bubo virginianus*) and March for late nesting species (i.e., most others). Patrols continued through May when raptor breeding activity ended. When a raptor or pair was observed, the location, species, group size, activity and habitat were recorded. When any raptor breeding behavior (e.g., courtship display, copulation, nest building, etc.) was observed, the frequency and duration of observations in that area increased. When construction of a nest or "nest start" had begun, the mining schedule and expected raptor breeding chronology were compared to determine the level of potential conflict. The need for a mitigation plan was then evaluated and developed if no reasonable alternative to the mining schedule could be identified. The FWS and WGFD were consulted, a mitigation plan developed and the appropriate wildlife permits obtained. The result of any mitigation action was documented through intensive monitoring.

Periodically, a pair would build a nest and lay egg(s) before the nest and/or pair were detected. An egg or brood manipulation was then considered.

RESULTS

Each manipulation consists of a Mitigation Proposal and Mitigation Actions or results. Each proposal includes the essential pre-mitigative alternatives and is presented here as developed prior to mitigation. Each result describes the execution of and outcome of each mitigative action.

Ferruginous Hawk

Mitigation Proposal

A FEHA nest (no. 7-8) and incubating adult were discovered in an essential mining area on a spoil pile on May 21, 1984. The nest site was in the path of a dragline and would have been affected within 3 weeks. To insure nesting success, mitigation actions were proposed. Intensive observations of the pair would begin immediately to determine use areas and favored perches of the adult hawks to determine the best location for moving the brood. The brood would be moved to a different nest (either no. 7-8A or 9-29) after hatching. Acceptance by both adults was important since the female generally feeds the brood and the male delivers prey. If the pair does not attend the brood at the new location, the chicks would be fostered to one or more other pairs.

Alternative nest no. 9-29 exists 1,640 ft. away in native habitat across the pit, in direct line of sight and in low disturbance. A man-made nest (no. 7-8A) would be placed 600 ft. from nest 7-8 on an adjacent spoil pile in a direction opposite the pit. Mining operations would be delayed to allow development of the chicks. Chicks less than 12 days old do not self-thermoregulate and must be brooded.

Mitigation Actions

Nest 9-29 had been inactive since before 1980 so sagebrush (Artemisia tridentata) twigs and cow dung were added to give it the appearance of an active nest. Man-made nest 7-8A was built from the same materials. Nest 9-29 was chosen as the nest for the chick move because it was more visible than nest 7-8A and the adult hawks were known to use the area. Three 13 day old chicks were moved to nest 9-29 from 0655 to

0735 on June 13. A frozen Richardsons ground squirrel (Citellus richardsoni) was placed in the nest near the chicks. The adult female landed on nest 9-29 at 1440 and soon fed the young. The male landed there at 1920. All 3 chicks fledged.

Red-tailed Hawk

Mitigation Proposal

Two RTHA nests (no. 7-23 and 7-26) and incubating adults were discovered on highwalls in essential mining areas on April 9 and 10, 1988. Blasting and dragline operations were scheduled well before self-thermoregulation of the young would occur. To insure nestling survival, mitigation actions were proposed. The 2 clutches would be transported in a portable incubator to a federally licensed raptor propagator, incubated, hatched and raised to an age conducive to fostering. Potential foster nests were checked prior to manipulation to insure that conspecific chicks were of similar age and that vacancies existed.

Mitigation Actions

Clutches of 5 and 3 eggs were removed from each nest, replaced with 3 plaster eggs and transported for 8 hrs. under incubation to a raptor breeding facility. The plaster eggs prevented the pairs from laying second clutches. Observations of the adults showed constant incubation and tolerance to blast pad construction and drilling directly overhead. Both nests were destroyed after the normal hatching period and after hawks were flushed from them and the area, just prior to the highwall reduction blasts. Neither pair laid second clutches. All 8 eggs were hatched and chicks were fostered (i.e, increased to no more than 4 total per nest) to nests on or near the mine permit area. All 8 chicks fledged, thus, production was preserved.

Prairie Falcon

Mitigation Proposal

A plan was developed in 1988 to mitigate potential impacts to a PRFA pair, during and after construction of an overland coal conveyor in 1989. Construction would occur near a falcon nest site which could preclude its use. Only one nest site existed for the pair as no alternative nest was known to exist. To insure a nesting opportunity, 2 mitigation actions were proposed. The first entails attracting the nesting pair to a new nest site built away from the conveyor. The second entails blocking access to the existing nest site (no. 3-1) located 200 ft. from the conveyor rights-of-way. The existing nest site and cliff was visually buffered from construction.

One nest cavity would be built in 1988 on a cliff approximately 950 ft. south of the planned east to west running conveyor. The site would buffer the falcon pair from sight and sound of construction and operation activities. The new site should not conflict with other raptor pairs in the area. The nearest reproductive pair in 1988 was a FEHA pair using nest no. 3-31. Nest 3-31 was located 1900 ft. from nest 3-1 and 1200 ft. from the proposed artificial nest. The entrance to nest 3-1 would be blocked while the conveyor is under construction to prevent its use.

A new cavity would be cut with hand tools or explosives, or an existing cavity would be filled with rock or modified so it has a flat and level floor. The cavity floor would cover at least 430 sq. in. and be at least 30 in. deep. These dimensions would allow for protection from weather and enough space for the normal physical development of the young. The cavity would be available for the 1989 breeding season. It would be constructed to have dimensions and characteristics selected by the species as nest sites and thereby be conducive to nest success. If the artificial site is selected by the falcon pair, no manipulations of young should be necessary.

Other potential ledges exist on the bluffs near nest 3-1 and the conveyor. Most of these, however, lack the correct dimensions or floor structure that would make them suitable for nesting. PRFAs, like other raptors, frequently choose alternate nest sites rather than nesting at the same site each year. None of these cavities has ever been recorded as a nest site and the pair has used nest 3-1 in all 8 of its breeding attempts since 1980. It was unlikely the pair would nest near nest 3-1.

If the PRFAs choose an alternative nest site on the same cliff as nest 3-1, BCC would be responsible for performing the approved mitigation actions. Manipulations may include: egg removal with artificial incubation, fostering of chicks, brood transfer to a platform and moving the platform.

The existing nest site (nest 3-1) and the associated cliff structure would be protected from construction by a 200 ft. buffer. An 8 ft. high fence would be built on the edge of the buffer zone along the conveyor corridor. Workers would be trained to observe the buffer zone. The obstruction would be removed from nest 3-1 after conveyor construction is complete so that the site is available for nesting when the conveyor is operating. The buffer zone and fence would remain after construction to protect the nest site from mining activities. Disturbances to the nesting falcons during operation of the conveyor should be negligible.

Mitigation Actions

In late 1988, the PRFA pair's access to nest 3-1 was blocked with welded wire and rocks. An artificial nest ledge was built using expanded metal covered with a clear plastic sheet, flat rocks and pea gravel. It was 48 in. deep and 29 in. wide providing 1,320 sq. in. of floor space.

Just prior to the 1989 raptor breeding period, nest 3-1 was checked to insure the obstruction was still in place. Also, the the artificial nest site was checked for its condition and to insure that a GHOW pair was not occupying the site. Use by a GHOW pair would prevent use by a PRFA pair.

The falcon pair was observed on the nest territory starting on March 20 and initially centered their activities around nest 3-1. By the end of March, their activity center had shifted to the artificial ledge. Copulation by the pair was observed on April 4. On April 7, a falcon was visible in incubation posture on the artificial ledge. Bulldozers and scrapers began work on a ridge cut for the conveyor on April 12. Topsoil was stockpiled 800 ft. from the artificial nest site, which was the closet contact between equipment and the nest site. Incubation by the falcons continued uninterrupted on that day, on April 12, 21 and 24, and in May. Attendance by the falcons during the brood rearing period was constant and considered normal. Corridor construction continued through June and conveyor assembly through the fledging period. No manipulation of the young was necessary. All 5 chicks fledged. A FEHA pair successfully nested (no. 3-31) simultaneously. The obstruction at nest 3-1 was removed after the breeding period.

CONCLUSION

Mitigation techniques were successfully used to resolve conflicts between nesting raptors and scheduled mining and construction. The ferruginous hawk manipulation demonstrated that an adult ferruginous hawk pair continued brood rearing and fledged their chicks even when those chicks were moved 1,640 ft. It also demonstrated that a ferruginous hawk conflict can be mitigated without reduction in nest productivity or delays in mining.

The egg manipulation demonstrated that conflicts involving red-tailed hawk eggs, and probably those of other species, can be mitigated while avoiding delays in mining, assuming that eggs and chicks are properly cared for and sufficient fostering opportunities exist.

The prairie falcon manipulation demonstrated that a prairie falcon pair not previously habituated to construction could breed successfully on a well designed and built artificial ledge 900 ft. from construction.

The success of these manipulations depended on a good understanding of the biology and behavior of each species. Use of these mitigation practices protects the breeding success and promotes the continued existence of individual raptor pairs, allows study of their tolerance to disturbance and handling, and allows more flexibility for mine operators.

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Planning, Rehabilitation and Treatment of Disturbed Lands
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POTENTIAL HIGHWALL USE BY RAPTORS IN COAL MINE RECLAMATION

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ABSTRACT

In 1982, Western Energy Company's Rosebud Mine, located in southeastern Montana, received legal exception, "a first" in Montana to leave a standing mine highwall extending a native bluff. This bluff extension stands 110 feet high and 900 feet long. Normally, all highwalls by law are reduced to a 5:1 slope. This legal exception was accomplished with the support of several governmental agencies and was justified on the highwalls potential value for raptors. Enhancement measures undertaken on the highwall included the construction of three artificial eryies and the release of young prairie falcons (Falco mexicanus) employing hacking methods of the Peregrine Fund. The hack is now in its fourth year with a total of 46 young falcons having been released. Opportunities exist for creating a more diverse habitat for raptors and other cliff obligate species on reclaimed mine lands in the west. It is believed that this practical approach should be explored.

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INTRODUCTION

This paper intends to show the merits of creating cliff features in coal mine reclamation in Montana. The addition of cliff features to our reclamation program greatly increases the range of topographic features possible on a reclaimed surface. These cliff features inturn provide habitat diversity and shelter for both wildlife and livestock.

It is generally recognized that reclamation at coal mines in Montana is meeting the intent of the regulations of the Surface Mining Control and Reclamation Act (SMARCA) and that the reclamation is working well. For the most part the west has not experienced the same problems which were associated with coal mines in the east. Reclamation diversity for cattle and wildlife is achieved by our program of seeding a diverse mixture of native grass forbs and shrubs.

Current regulations require land disturbed by coal mining be reclaimed to the pre-mine land use, Rule 26-4-762. Also, Rule 26-4-501A states that all final regrade must be to the approximate original contour.

Our pre-mine contours are exemplified by wide open valleys with steep rugged buttes. Small isolated sandstone outcrops protrude on the landscape providing natural cliff features. Following mining the reclaimed topography is modified. The topography is consistent with the regulations dealing with approximate original contours but the overall landscape is smoothed, exhibiting a more rolling topography. Current regulations assure this outcome because the major emphasis of the regulations mandate a stable non-erosive reclaimed surface following mining, not allowing steep slopes, incised drainages or active erosional features to occur.

Topographic diversity however, could most practically be increased by the addition of mine created cliffs. Unfortunately, current regulations prohibit cliff highwall establishment as a normal postmine reclamation feature except in very limited situations such as to extend an existing bluff under the alternate reclamation rules (Rule 26.4.515). The extension of an existing bluff is thought to be consistant with regulations pertaining to approximate original contour. Using the bluff extension criteria, Western Energy was successful in 1982 in receiving legal exception, a "first" in Montana, to leave a standing highwall (WECO, 1982). It effectively extended an existing bluff locally known as "Gobbler's Knob". Western Energy was successful through the support of the Montana Department of State Lands, U.S. Fish and Wildlife Service, Montana

Department of Fish, Wildlife and Parks and other agencies. This bluff extension was largely justified on the bluffs potential value for wildlife, particularly raptors. A raptor enhancement plan was formulated for the cliff and implementation began in 1982. The construction of nesting cavities and the release of prairie falcons (Falco mexicanus) were part of the plan.

ALTERNATE RECLAMATION PLAN FOR GOBBLER'S KNOB A HISTORY

In 1980, Western Energy encountered an unusual situation in its Area E mine. A final pit abutted a large landmark butte locally known as Gobbler's Knob. This natural butte has an elevation of 3,575 feet and from its base, rises abruptly 175 feet. The final mine pit and its associated highwall wraps around the east end of the butte. The pit effectively increased the height of the buttes by 110 feet.

Montana Strip and Underground rules and regulations require highwalls to be reduced to a 5:1 slope or 20% grade (rule 26.4.515). The question arose, "Do we want to reduce the highwall and therefore Gobbler's Knob butte to meet highwall reduction requirements? Or do we leave a cliff at the front edge of Gobbler's Knob thereby leaving the butte intact? In other words, meeting the legal 5:1 slope would have necessitated increasing our disturbance area which would have resulted in three/fourths of the butte being knocked down. At the time WECO had three alternatives it could pursue:

1) Reduce the final highwall to 3:1 slopes as specified in the permit. This option would necessitate additional disturbance to some point beyond the highwall and require extending the present permit limit. The result would be slopes of questionable stability with respect to erosion and require special revegetation and regrading techniques.

2) Reduce the final highwall to 5:1 slopes. This option would necessitate permitting all of the presently unpermitted surface over and around Gobbler's Knob. Regrading to 5:1 slopes would unquestionably be preferable to 3:1 slopes from a stability and erosion standpoint, however, the "Gobbler's Knob" land form would be obliterated in the process. This would be an example of maximum disturbance of non-coal producing surface land. It is generally agreed the resultant smooth 5:1 slopes would not be compatible with existing undisturbed terrain and would not be aesthetically pleasing.

3) Leave a portion of the final highwall as an exposed cliff face. This option offered numerous advantages over the first two alternatives. In the first place, disturbance of previously undisturbed surface land is kept to an absolute minimum. Gobbler's Knob, as a geomorphic feature, would remain intact. The resultant landscape would effectively blend into the existing topography and more nearly approximate the original contours. And, finally, the standing highwall would create cliff-type habitat, which is considered to be a wildlife enhancement feature, that would add diversity to the reclamation.

WECO made a decision to pursue legal exception and leave the highwall and therefore the native bluff. That decision was primarily based on the importance of Gobbler's Knob as a local landmark which would be lost if reduced. A secondary consideration was that the highwall would provide diversity of habitat and vegetation. Highwall reduction would also result in the loss of topographic relief. Mining costs would be decreased if it were left standing. Finally, it would provide cliff habitat and enhance our reclamation diversity for raptors and other cliff obligate species.

The Wyoming Mining Association in a recent report entitled, Regulation Reform Allowing Establishment of Bluffs as Final Mined Land Reclamation at Coal Mines in Wyoming (1988) listed the benefits of leaving properly designed bluffs in final mined land reclamation as follows:

-- Creation of topographic diversity.

-- Reestablishment of terrestrial wildlife habitat that is lost due to elimination of gullies, steep slopes, etc.

-- Enhancement of vegetation in post-mining plant communities.

-- Establishment of areas which provide shelter to livestock and wildlife during severe storms.

-- Establishment of areas which provide shade to livestock and wildlife during hot weather.

-- Creation of suitable nesting and perching areas for raptors.

-- Minimization of the amount of land disturbed by mining (by lessening amount of highwall reduction and "back-grading").

-- Potential cost savings to the coal mine operator.

-- Possible increases in mineable reserves and taxes to the State.

Approval For WECO's bluff extension plan was given by the Department of State Lands and the Office of Surface Mining in August of 1982.

WECO felt that the highwall would serve some of the same functions as the native standstone outcrops which are found through out our region. The highwall could provide habitat for one or more of the following species of birds for nesting, roosting, hunting and perching: Great horned owls (*Bubo virginianus*), Prairie falcon (*Falco mexicanus*), Golden eagle (*Aquila chrysaetos*), Mountain bluebird (*Sialin currucoides*), Rock wren (*Catherpes mexicanus*), American kestrel(*Falco sparrurius*), Cliff swallow (*Petrochelidon pyrrhonota*), Say's phoebe (*Sayornis saya*) and others.

Western Energy has documented use of active highwalls by American kestrels, Cliff swallow and Rock wrens (WECO, 1987). Schwarzkoph (1980) was successful in moving three young Great horned owls which had nested on an active highwall at Colstrip. Since that time Western Energy Company has documented three other Great horned owl nests on active highwalls (WECO, 1988).

CLIFF ENHANCEMENT FOR RAPTORS

In receiving approval of the highwall, it was stipulated that a raptor enhancement plan be completed. A plan was formulated in cooperation with the U.S. Fish and Wildlife Service, The Montana Department of Fish, Wildlife, and Parks, and Western Energy Co. Artificial eyries(nesting cavities), constructed for prairie falcon occupancy was the major element of the enhancement plan. Artificial eyries have been suggested as a viable raptor management tool (Olendorff and Stoddart, 1974; Call, 1979; Fyle and Armbruster, 1977; Crawford and Postovit, 1978).

Two techniques that can be used to construct suitable cavities in consolidated rock are excavating with hand tools, and/or drilling and blasting. The second approach was preferred. A Consolidation Coal Company employee from Sheridan, Wyoming, Earl Smith, who had developed a novel approach (Smith, 1985) for constructing artificial Prairie falcon eyries was contacted to help with the construction plans. A brief description of this techniques follows.

First an explosive, referred to as a shape charge, was used. Shape charges were developed by the military for the purpose of penetrating armor. The military could stick a shape charge to the outside of a tank and blow a hole inward. The shape charge works on the Monroe principle. Being conical in shape, it concentrates its explosive force like a magnifying glass concentrates light.

Nine shape charges were glued to a heavy cardboard and connected with detonating cord. The sheet was secured to the cliff face at the designated position with concrete nails. The charge was then fired from the safety of the top of the cliff as shrapnel-like pieces of casting were propelled at potentially lethal velocities. The nine holes punch into the cliff face by the shape charges were conical rather than cylindrical. A hand held auger with a T handle was used to ream the holes to a depth of 40 centimeters in preparation for the next step.

Deta prime, a plastic explosive, was placed in each of the nine holes. A detonating cord was connected to the explosives. The charges were timed to explode in a specific pattern and sequence which resulted in a clean rectangular cavity. Hand tools were not needed for final shaping. Three cavities were constructed on the highwall using these methods (Figure 1).

In 1986, WECO began a four year prairie falcon release program at the highwall site. The Peregrine Fund, Inc. hacking and release procedures (The Peregrine Fund, 1982) were employed during four releases. A total of 46 birds have been released to date (The Peregrine Fund, 1982). No falcons have returned and established a territory on the highwall, however, numerous falcon observations have been made.

The odds of territory establishment by our falcons is understandably low when looking at the estimated survival rate for prairie falcons. Survival to the first year is estimated to be between 18 to 44 percent. Survival is estimated to be between 50 to 80 percent each year after (Runde, 1986). Prairie falcons are generally sexually mature at two years of age. When this is coupled with the survival rates the potential return of breeding falcons to Gobbler's Knob (Figure 2). The figures are based on a release of nine birds in 1986, nine in 1987, fourteen in 1988, fourteen in 1989 and assumes a fourteen bird released in 1990.

SUMMARY

In summary, reference is made to a Master of Science thesis done at the University of Wyoming titled Effects of Cliffs On Wildlife Communities Located on High Altitude Shortgrass Prairie by John Ward, (1987). It was concluded that "... the cliff's presence also directly benefited some wildlife species that hilly terrain could not have provided." He goes on to note that when compared to rolling grassland sites, "...cliff sites generally had a high diversity of soils and vegetation which increase small mammal and bird diversity and abundances in the area." Generally speaking, the more homogeneous the vegetation and topography of an area, the greater the benefit derived from the inclusion of unique features such as bluffs, cliffs, and rimrocks. Current rules and regulations do not allow for unstable erosive landforms which would create topographic diversity. The regulations were in fact designed to prevent many of these features from occuring. Mine created cliff-like features would be a very practical way of increasing topographic diversity on reclaimed mine lands in the west.

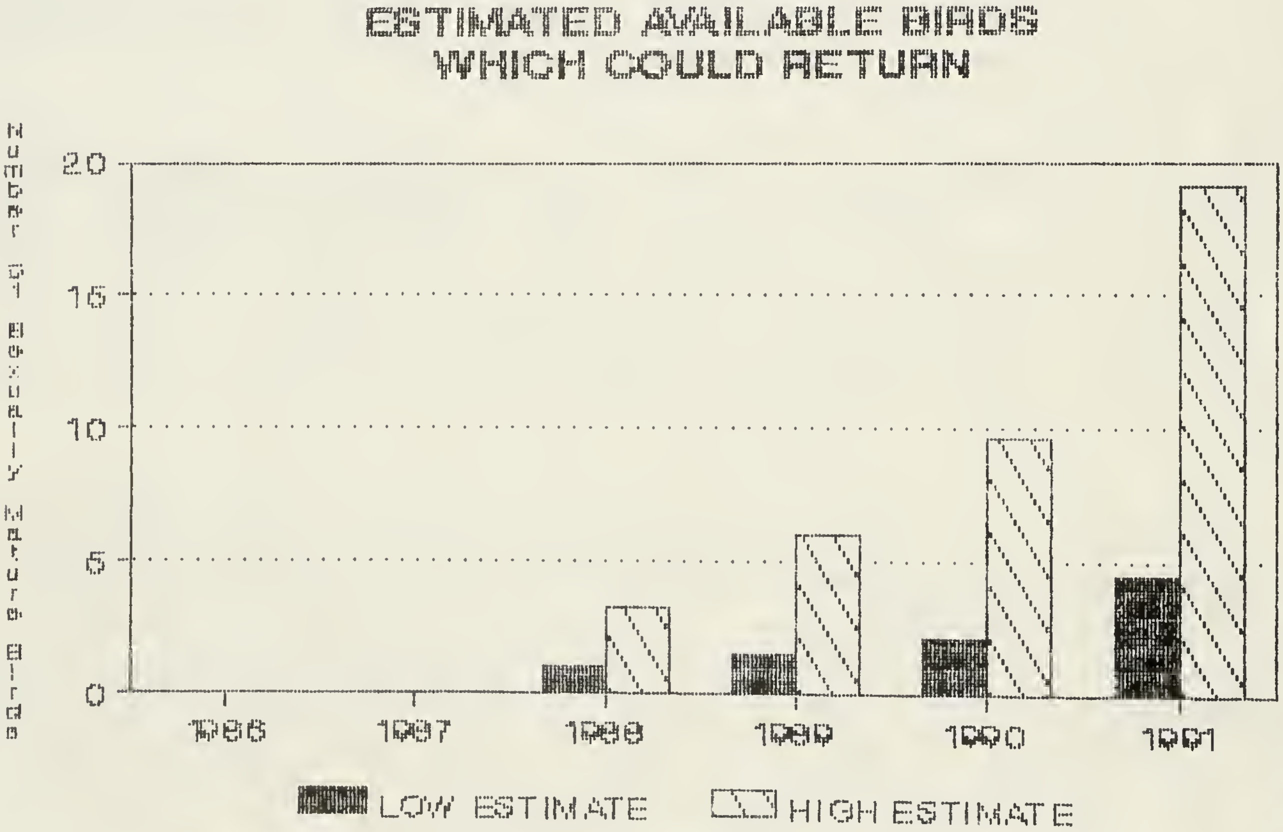

Figure 2

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Analysis of a Wyoming Program Amendment Attempt for Wildlife

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ABSTRACT

The 1977 advent of SMCRA emphasized the heightened concerns for effective reclamation of coal mine disturbance. Many, if not all, EIS documents of this era foretold mining activities bringing catastrophic impacts to local and even regional wildlife communities. With eleven years hindsight, regulators, environmental interest groups, land owners, and industry now recognize this as a gross miscalculation. Working, sometimes together and sometimes in opposition, the diverse special interest groups all have developed an understanding of the results of mine development under SMCRA. In Wyoming, currently there is a general consensus that mining can be compatible with wildlife, and that reclamation is possible. However, it has been perceived that even though mine reclamation has been successful, wildlife habitat restoration has not always been so satisfactory. In many instances this resulted from either conflicts within SMCRA, or SMCRA provisions repressing other pertinent regulations. Through the years Wyoming's Permanent Program regulations have been modified many times, for several reasons. In mid-1987 a group of mining companies sought to initiate another program revision, this time specifically for the benefit of wildlife. This revision would allow the construction of bluff features to replace or enhance wildlife habitat on coal mine reclamation. Relevant state and federal agencies, as well as environmental interest organizations were invited early on to participate in the planning, development and "selling" of the effort. The concept brought forth coincidental benefits for many other interests. This paper describes the thought processes behind the project's conception, and the approach used to develop and guide the Wyoming State Program Amendment through the regulatory approval system. For political reasons, OSM's ultimate rejection of the proposal ignored the environmental benefits and widespread support for the concept.

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BACKGROUND

Current Reclamation Status

In 1977, the United States Congress passed the landmark Surface Mine Control and Reclamation Act (SMCRA). SMCRA has proven one of the most complex and controversial environmental programs ever implemented in this country. Driven by over a century of non-regulated mining abuses, particularly in eastern coal fields, this law emphasized the heightened national concerns for effective reclamation of coal mine disturbance. In Wyoming, there currently is a general concensus that even though mine reclamation within the state has been successful (e.g. good plant cover and diversity, and erosional stability), wildlife habitat restoration has not been as successful. An over emphasis on particular aspects of SMCRA, such as Erosional Stability, and a misapplication of the Approximate Original Contour concept, is effectively eliminating much of the crucial topographic diversity present prior to mining (i.e.. deep gullies, badlands, etc.). It is this topographic diversity which allows many species of wildlife to exist, and livestock to fully utilize native prairie and shrub-steppe environments.

The unconsolidated nature of material backfilled into mined out pits, makes it impractical to recreate the deep gully/badland type erosional features, and still satisfy SMCRA provisions requiring erosional stability. Therefore, a pre-post mining slope analysis shows a general flattening of most mine area reclaimed topography.

Pertinent SMCRA Sections

The Wyoming Department of Environmental Quality - Land Quality Division is responsible for administering the provisions of SMCRA within the state, through the Wyoming Environmental Quality Act and the Land Quality Division Rules and Regulations. These LQD Rules and Regulations comprise the Wyoming State Regulatory Program, and must be reviewed and approved by OSM. The primary criteria for approval is that State Program provisions can be no less stringent than SMCRA. Several aspects of SMCRA pertain to possible efforts for restoration of suitable wildlife habitats on reclaimed areas. It is these parts of SMCRA which either will preclude some possibilities, or must support any regulatory changes suggested for the Wyoming Program Regulations.

Section 101 Findings:

c) many surface mining operations result in disturbances...that burden and adversely effect...public welfare...by destroying fish and wildlife habitats...,

e) effective and reasonable regulation...in accordance with the requirements of this Act is an appropriate and necessary means to minimize so far as practicable the adverse ...environmental effects of such mining operations;

f) allows states to develop regulations that vary from Federal rules based on differences in terrain, climate, and biological and physical conditions.

Section 515 Environmental Protection Performance Standards:

b) ...require the operation as a minimum to --

2) restore the land affected to a condition capable of supporting the uses which it was capable of supporting prior to any mining, or higher or better uses of which there is reasonable likelihood, so long as such use or uses do not present any actual or probable hazard to public health or safety...

3) for all surface coal mining operations backfill, compact..., and grade in order to restore AOC of the land with all highwalls...eliminated...(not totally reduced or backfilled):
   - o thin o.b. conditions: "angle of repose" acceptable for all available overburden
   - o thick o.b. conditions: AOC within disturbance, and "angle or repose" on excess o.b. and other spoil and waste materials.

24) to the extent possible using the best technology currently available, minimize disturbances and adverse impacts of the operation on fish, wildlife and related environmental values, and achieve enhancement of such resources where practicable;

Section 701 Definitions:

2) AOC means that the surface configuration achieved by backfilling and grading...closely resembles the general surface configuration of the land prior...to mining...with all highwalls and spoil piles eliminated...
   - o in 1977, The U. S. House of Representatives recognized that "AOC is, of necessity, a flexible standard which contemplates different mining circumstances."

Pertinent Literature

Mine pit backfill material's unconsolidated nature precludes recreation of steep slope habitats because of its erosive properties. Therefore, the only location this type of habitat structure can be developed, is at the backfill-undisturbed surface interface. The important question to first ask before proposing incorporating special features into reclamation was stated by the Wyoming Game and Fish Department (1976) "Is there a need for this type of development for wildlife?" In many cases the answer is clearly yes! The unique opportunity that mining offers to enhance these areas is alluded to by Maser et. al (1979) in their comments regarding cliff/rimrock features: "These habitats 'come issued' with the land and cannot, for the most part, be created through land management activities." They further note, "These habitats cannot be artificially created without great expense...". Strip mining provides an economical opportunity to enhance topographic diversity through the construction of bluff type features from final mine pit sites.

Many authors have espoused creation of bluff/cliff/rimrock type habitat in mined land reclamation. Others, apparently not aware of SMCRA's specific requirement to eliminate highwalls, suggest leaving them as wildlife habitat. Kearney and Oelklaus (1988) summarize a comprehensive review of this literature. Suffice it to say, this literature covers a variety of authorships: federal land and wildlife management agencies (U.S. and Canadian); state wildlife, land management, and regulatory agencies; federal judicial decisions; mining companies; public environmental organizations (consultants and advocacy groups), and private citizens. Perhaps most note worthy are the reports of federal studies charged with assessing effects of SMCRA. The reader is referred to : Hinkle et al. (1981)), a handbook for meeting fish and wildlife information needs to surface mine coal - OSM Region V; Committee on Highwalls and Approximate Original Contour (1984), Highwall elimination and return to approximate original contour as required in the Surface Mining Control and Reclamation Act of 1977; Interstate Mining Compact (1984), Elimination of highwalls. Significant issue report number One; Office of Technology Assessment (1986), Western surface mine permitting and reclamation.

Currently Acceptable Steep Slope/Highwall Reclamation

The Wyoming Abandoned Mined Lands program, which is responsible for eliminating hazards to public health and safety, property and the environment, has reclaimed several coal and non coal mines where portions of mine highwalls were actually left as bluff-type features. According to Gary Beach, Abandoned Mine Lands Program Manager, these bluff-type features were retained to provide raptor and wildlife habitat (the sites were often used for raptor nesting prior to reclamation). The retention of these types of features at Abandoned Mined Lands sites throughout Wyoming also results in cost savings as backfill and highwall reduction costs are reduced (Beach 1988. Personnel Communication). Bluff type topographic features are positive reclamation features which have been proven valuable in the State of Wyoming (Ward and Anderson 1987).

As noted earlier, SMCRA also provides exemptions from AOC for specified conditions. Where the depth of overburden is very low relative to the coal seam thickness, the mine is considered as a "thin overburden mine". As such, overburden may be graded as steep as angle of repose for final reclaimed surfaces. A thin overburden condition is prevalent throughout the Powder River Basin region. For mines with the opposite condition, (overburden depth greater than coal seam thickness - a "thick overburden mine"), all regraded surfaces within the disturbances must meet AOC. Excess overburden spoils may be graded to angle of repose. In either of these cases, all highwalls must be eliminated (SMCRA: Section 515.b.3). In almost all instances, backfill angle of repose slopes have proven erosionally unstable.

INITIATION OF THIS REGULATORY REFORM EFFORT

Early Mine Company Efforts

Our parent company, NERCO, Inc., has examined numerous possibilities of regulatory reform which would enhance either coal recovery or reclamation efforts. Corporate task forces in 1978, 1984 and 1987 were assigned with the responsibility to identify significant issues to improve our mining activities. Each of these efforts identified some form of highwall reduction relief as a highly beneficial approach. However, the regulatory climate was adjudged non-conducive to the proposal developed, and the first two efforts never were carried outside of the corporate environment.

Conversations with many persons within the coal mining business, revealed a broad concensus for the potential benefits from some form of highwall reduction relief. Arch Mineral Corporation's Seminoe I mine near Hanna, Wyoming, seems to have been the first instance of a highwall approved for retention within a reclaimed area. The uniqueness of this effort is reflected in its mention in virtually every mined-land reclamation publication discussing landforms since approval of their Experimental Practice Variance in 1983. Extensive post-reclamation monitoring of the area documented that the site compared favorably with natural cliffs within the region (Ward 1987, and Ward and Anderson 1987). Ward (1987) concluded "If the highwall was regraded and eliminated, many of the wildlife species observed would have been absent from the area." A similar variance was subsequently obtained in southern Montana by Western Energy Company. Their "Gobbler's Knob" site near Colstrip, Montana was described as "...essentially creating this type of habitat (sandstone outcrops or cliffs) where there was none before." (Leedy et. al. 1987). Approval of both of these plans took over two years of regulatory efforts, and incurred very high costs (Ward and Anderson 1987, Leedy et. al. 1987).

Similar Provisions In Other State Programs

New Mexico

The approved State Program for New Mexico provides that portions of highwalls may be retained upon approval of the Director (New Mexico Surface Mining Rules 1656:0577 Section 20-102.a.2). The six conditions which must be met include safety concerns, backfill coverage of the uppermost minable coal seam, the replacement of cliff type features eradicated by mining activities, and restrictions on the extent and configuration of highwall portions left standing.

Montana - Utah

Both Montana and Utah have provisions similar to those in the New Mexico regulations. However, their language is generally less specific. Montana language refers to "bluff extensions" which in practice may result in either horizontal or vertical extensions of natural features.

Formation of a Wyoming Mining Association Committee

Based on the information and assessments outlined above, the broad-based benefits of constructing bluff-type features made further pursuit of this goal worthwhile. The subject was broached with other mining companies in Wyoming. Each expressed an interest, or in several cases willingness to actively work on the project. It was determined the most appropriate forum for development of the effort was under the auspices of the Wyoming Mining Association, an organization representing mining interests of the state, with a membership of 38 mining and 140 service companies which employ over 10,000 persons. The Ad Hoc committee was formally installed in November 1987. Representatives from NERCO Coal Corporation, Powder River Coal Company, Thunder Basin Coal Company, and Cordero Mining Company formed this sub-committee of the WMA Regulatory Agencies Committee. The first major undertaking of this group was to develop a position paper outlining the regulatory reform effort, and detailing the benefits (Kearney and Oelklaus 1988). This paper served as the vehicle to introduce our effort to all groups later contacted in developing support for this regulatory reform effort.

From the committee's first discussions, it was obvious the success of the entire endeavor rested on a relatively few specific points. How to address two key points of SMCRA: Approximate Original Contour, and what would constitute highwall elimination. It was also obvious that the effort would receive the scrutiny of numerous regulatory agencies and a wide variety of environmental organizations.

DEVELOPMENT OF THE PROPOSED REGULATION DRAFT

The WMA sub-committee enlisted the aid of three other groups to participate as a "working group" in development of the idea, and a draft of proposed regulatory language. First, the Wyoming Department of Environmental Quality-Land Quality Division, the state agency charged with regulating all coal mining activities in the state. The Wyoming Game and Fish Department brought their obvious expertise to the effort. Also, the Wyoming Wildlife Federation was invited to participate as the largest, most active of Wyoming's environmental organizations.

Throughout development of the initial regulatory revision draft the discussions repeatedly swung back and forth between technical, environmental, operational and regulatory considerations. We quickly reached the conclusion that no change to SMCRA was necessary, or desirable. The goal of this proposal was thus to modify the Wyoming Department of Environmental Quality-Land Quality Division Rules and Regulations to allow the establishment of bluff type features as an acceptable reclamation practice at coal mines in Wyoming. The acceptance of such a proposal and its subsequent implementation would go far towards resolving the conflicts within the regulations and would allow the enhancement and creation of valuable habitats. Members of this working group made a conscientious effort to contact all groups which we felt would have an interest in the proposed regulatory revision, or could provide useful input to strengthen the effort (i.e. OSM, BLM, Forest Service, U.S. Fish and Wildlife Service, University of Wyoming, Wyoming Department of State Lands, Wyoming Chapter Wildlife Society, Society of Range Management, Wyoming Outdoor Council, Powder River Basin Resource Council, Sierra Club, Wyoming Farm Bureau Federation, Wyoming Woolgrowers

Association, Wyoming Stockgrowers Association, and private landowners). Representatives from most of these groups attended a public informational meeting on 14 July 1988. Discussions generated by the presentations highlighted many concerns, as well as providing useful suggestions.

It was obvious that addressing all important aspects would produce cumbersome, confusing regulatory language. Therefore, the effort was revised to produce two documents. First the actual additions and revisions to the WDEQ-LQD Rules and Regulations. A Guideline draft was also developed to expand upon the more succinct regulatory language. This second document detailed construction and safety standards, as well as environmental, permitting and justification considerations necessary to develop an acceptable, approveable reclamation feature. Together these documents would provide a mine operator with the knowledge of what was necessary for approval, the regulators with guidance in what to look for in reviewing permit submittals, and the general public assurance these features would be useful, feasible and not present a safety hazard. As a key point, it was decided each constructed bluff permit request would require a public notice. This would ensure notification and ample opportunity for public comment before state regulatory approval.

WYOMING APPROVAL PROCESS

Revisions to the Wyoming Rules and Regulations pass through a defined approval process. As this proposal would revise these Rules and Regulations, it passed through the complete regulatory approval process.

The working group finalized the proposed revisions/additions to the WDEQ-LQD Rules and Regulations, and submitted them to the Wyoming Environmental Quality Council for rulemaking on August 15, 1988. Co-petitioners were the Wyoming Mining Association, Wyoming Game and Fish Department, Wyoming Wildlife Federation, Powder River Coal Company, NERCO Coal Corporation, Thunder Basin Coal Company, and Cordero Mining Company. The forty-five day public notice period initiated August 19th.

In September presentations were made to the OSM - Washington D.C. office and the OSM - Western Technical Center in Denver. Discussions with the Wyoming Congressional delegation and staffs during this time served to keep them appraised of the project's status. A public hearing was held before the Wyoming Land Quality Advisory Board on October 3rd.

On October 7th, the Wyoming Environmental Quality Council held their hearing on this rulemaking petition. Public comment at the meeting was very limited, and all in favor of adoption. The single negative letter received by the Council, was overwhelmed by the preponderance of supportive letters. Virtually all organizations/persons contacted during the proposal's development, provided written support to the Council. Council members raised several points, requesting assurances and clarifications. It was gratifying to note that all but one of the points they questioned (a semantic change) had been discussed and addressed by the sub-committee.

Approval of the rulemaking proposal by the Council, with their single suggested wording change, moved the process on to its next step. The LQD submitted the proposed Rules changes to the Wyoming Attorney General's office on October 21st. Their review and recommendations assuring legality with Wyoming law accompanied the package to the Governor's office. On November 21st, members of the WMA sub-committee, LQD, Game and Fish Department and the Governor's office staff met to review the proposal, and discuss its subsequent presentation to OSM.

The LQD developed a comprehensive "statement of reasons" and strong "statement of transmittal" with the support of the WMA sub-committee. These "statements" summarized the projects potential value and applicability, hopefully clarifying OSM's subsequent review. The Rule revision was filed with the Wyoming Secretary of State effective December 5th, and transmitted to the Director of OSM on December 13th, along with public comment letters, EQC hearing findings and the WMA background paper. Key points made in these materials included the widespread support throughout the state, the concept's applicability within Wyoming's natural environment and regulatory framework, and how the proposed Rules fit within provisions of SMCRA.

INITIAL OFFICE OF SURFACE MINING REVIEW

The OSM published their Opportunity for Public Hearing on the proposed Wyoming Rule amendment in the Federal Register on January 13, 1989. Written comments from the "interested public" were received from most who provided comments to the Wyoming Environmental Quality Council. Negative responses received at this time were again limited. However, their tone represented a decidedly new shift. Out-of-state environmental activist organizations commented for the first time. Their approach did not recognize construction of a bluff feature from a highwall as "highwall elimination". Further they argued the proposal would not meet the provisions of Approximate Original Contour. They generally concluded the proposal was an attempt at "leaving highwalls" to benefit livestock or wildlife.

The Wyoming Wildlife Federation, until this time a participant in discussions and development of the proposal, submitted a letter describing their position thusly: "   we cannot allow our support to be interpreted as anything but wavering." From conversations subsequent to their letter, Federation representatives clearly explained that "out-of-state" organizations had convinced them that the Wyoming proposal was a transgression against SMCRA, and illegal as well. Clearly, the feelings expressed by the WWF representative during the very first meeting attended, continued to prevail: that is, an uncomfortableness because in the past the participants in the meeting were generally in a confrontational situation.

Even the Wyoming Game and Fish Department letter response was anything but fully supportive, and this from a group which had been fully involved in the entire process, as well as integral to development of the technical specifications and mandated regulatory processes. Their letter reiterated internal state squabbles over a desire to acquire some degree of authority for approval of "bluff" projects submitted for consideration under the proposed regulation amendment. The total extent of their expression of support was limited to a single sentence alluding to their "...oral and written testimony of support..." presented earlier to the Wyoming Environmental Quality Council.

Following the tenor of comments received by the EQC, no commentor questioned the value or potential benefit of constructed bluffs on reclaimed areas in Wyoming. In fact, many commentors made these values and benefits the basis of their support.

On March 29, 1989, OSM sent a letter to the Wyoming Department of Environmental Quality - Land Quality Division expressing that "The Director finds that the proposal has merit; however, in order for it to be no less stringent and no less effective than...SMCRA and the applicable Federal regulations, the proposal must be modified...". The points requiring clarification included questions of return of AOC, each features providing wildlife value, restrictions on extent of bluffs consistent with their environmental justification, as well as insurance of safety standards. They specifically directed that the definition of a bluff "...should clearly state that this definition shall not be interpreted as allowing the retention of an unreconstructed or unmodified highwall unless the highwall replaces preexisting natural features with similar characteristics." This wording generally reflects that currently approved in the New Mexico Program.

ADDRESSING THE OFFICE OF SURFACE MINING CONCERNS

The general tone of the March 29th OSM letter was felt to be quite positive. Their concerns centered on those aspects of SMCRA considered as the key points to address since initiation of this effort. All of the OSM concerns were thoroughly discussed and debated during development of the proposed Rules revisions and supporting Guideline. In their letter OSM stated that:

> "These provisions of SMCRA do not prohibit the restoration or creation of vertical or near-vertical topographic features where such features would restore or complement the natural topography of the area and where they would be compatible with the approved postmining land use. The context of the statutory prohibition on highwall retention indicates that Congress considered highwalls only in the sense that they are creations of mining which are unaesthetic, pose a significant impediment to beneficial use of the land following mining and represent potential safety and stability problems. There is no suggestion that Congress intended to prohibit the creation of safe, erosionally stable bluffs to replace natural features destroyed by mining unless doing so would conflict with the approved postmining land use."

OSM therefore stated that to obtain approval, the proposed Wyoming Rule revision would need to require documentation of "...preexisting natural erosional features (steep draws, gullies, scoria outcrops, badlands, etc.) within the area to be mined." They continue on to state that restoration of these features "...need not necessarily be restored in form location or extent to which they originally occurred..." They also pointed out that "... any bluff creation proposed as a substitute for these features would complement the approved postmining land use, blend with the local topography and restore or enhance fish, wildlife, or related environmental values. OSMRE recognizes that it is impractical and usually undesirable to create exact replicas of erosionally unstable natural features. However, bluffs must be designed and constructed to blend with and replicate the beneficial aspects of such features."

A final key point conceeded by OSM showed their recognition that modification of a highwall to create another feature, in this case a bluff, constituted highwall elimination under SMCRA, especially where other conditions of SMCRA were expressly addressed by the effort:

> "In addition, Section 515(b)(24) of SMCRA requires that operators, to the extent possible, using the best technology currently available, minimize disturbance of, and adverse impacts on, fish, wildlife and related environmental values, and achieve enhancement of such resources where practicable. The underlined phrase may be interpreted as encouraging, to a limited extent, the modification of highwalls to create bluff-type features such as those proposed by Wyoming, provided the bluffs are compatible with the approved postmining land use and are designed and constructed to achieve enhancement of fish, wildlife and related environmental values. Properly modified to achieve this purpose and to minimize potential aesthetic, safety and hydrologic concerns, these bluffs would no longer be considered highwalls requiring elimination under Section 515(b)(3) of SMCRA."

To address the conditions raised by OSM, the LQD convened a series of meetings with WMA sub-committee, Game and Fish, and Wyoming Wildlife Federation representatives. Having covered all of these points (as well as many others) at great length over the past year, the thrust of these discussions was how to best accommodate OSM's requirements, and what language would most clearly establish the intent of the rule revision. In all but one instance the OSM suggestions were acquiesced to, even though our lengthy discussions to date showed no justifiable rationale for some regulatory constraints (i.e. there seemed to be no environmental reasons to limit height, length or number of properly designed bluff features; but apparently there were some political reasons as such limitations were specifically called for by OSM). Many of OSM's concerns were addressed by incorporating language from the Guideline document into the actual Rule language.

The single point of departure from OSM's direction involved allowance for retention of highwall segments. Even though such a provision was approved by OSM in the New Mexico Program, we felt we did not want that option in Wyoming's Program. Our rationale was that if we were going to allow a "bluff type structure", it should include environmentally useful features. Replacing a mined-out cliff with a stark highwall was not an alternative we wanted in Wyoming's Rules. Therefore, on this point we chose to clearly make Wyoming's Rules more stringent than SMCRA allowed.

During the Wyoming review of OSM concerns, and redrafting of rule language as well as supporting documents, two other significant events transpired. The proposal's publication in the Federal Register caught the attention of several environmental activist organizations outside of Wyoming. Without comprehensive review of the Wyoming Rule revision, several of these groups decided this was merely an attempt to circumvent highwall elimination and/or AOC provisions of SMCRA. This incorrect assumption not withstanding, none of them seemed to acknowledge the positive view that other provisions of SMCRA were addressed (i.e: enhancement of wildlife valves or actual compliance with AOC). Also, OSM in their March 29 letter state that bluff construction would constitute highwall elimination under the Environmental Performance Standards of SMCRA (Section 515.b.3).

Pressure from these Washington D.C. headquarter offices, of national special interest environmental groups intensified. Their contact with Representative Morris Udall and his staff resulted in contacts with OSM expressing apprehension over the effects of the Wyoming Rule revision effort. On April 25th, Mr. Udall sent a letter to Secretary Manual Lujan (USDI), requesting approval be withheld until the House Committee on Interior and Insular Affairs "...has been further briefed on the issue".

During this time period, the Wyoming Wildlife Federation support for the project deteriorated still further. On May 2nd, they sent a letter to LQD withdrawing their support for the Wyoming Rule revision effort. They described a concern that approval of this revision could "...be used to substantially weaken section 515(b)(3) of SMCRA. Their concern was based upon a preception of out-of-state environmental groups, that a "...collusion between OSMRE and the coal industry regarding the Wyoming highwalls proposal..." desired to "do away" with the SMCRA highwall elimination provision. They also expressed a fear that outgoing OSM officials from the previous administration "...cannot be trusted to uphold the agency's environmental responsibilities...". WWF continue to note that the constructed bluff concept was "...a good idea for reclamation in Wyoming...", but could become a tool for nationwide deregulation of the coal industry.

After several working group meetings, as well as clarification meetings with OSM, LQD submitted Wyoming's responses to the March 31 letter to OSM. On September 7, 1989, OSM published in the Federal Register, reopening and extending the public comment period in acknowledgement of their "...receipt of additional explanatory information and revisions...". Following submittal, Governor Sullivan met with Secretary Lujan, and new Director of the U.S. Fish and Wildlife Service, John Turner, expressing the State's interest and his support of the proposed Rule revisions. Wyoming's Congressional delegation again submitted a strongly supportive letter to OSM. Numerous additional letters were submitted to OSM during this response period. In general, their tone took one of two opposing directions. The majority assumed a supportive stance citing enhancement of wildlife values, returning reclaimed lands to a capability equal to or greater than existing pre-mining, special applicability to Western environmental conditions, and "constructed bluffs" meeting the criteria for "highwall elimination". Of the opposite opinion, negative commentors usually called into question the proposed Rule's meeting of the AOC and "highwall elimination" provisions; often precedence setting for Eastern states was also mentioned.

As can be seen, the key points either in support or opposition remain those identified at the project's inception. Opponents do not seem to be concerned with the project's environmental value or effects. In fact, many of these commentors express the belief that the proposal would serve to significantly enhance Wyoming reclamation efforts for wildlife.

OFFICIAL OFFICE OF SURFACE MINING RESPONSE

On December 22, 1989, OSM notified the State of Wyoming that OSM's decision on the proposed bluff Rule revision would appear in the December

26 Federal Register; a copy of that notice was attached. OSM decision was to disapprove the proposed amendment, now referred to as allowing "...retention of highwall remnants as final reclamation features where such features would benefit wildlife and livestock." Supplemental Information summarized the Federal activity process to date, and explained the basis for their decision.

The Director found that the significant potential benefits of wildlife enhancement, which could "under certain conditions" be restored or enhanced by the Wyoming proposal, did not "...provide a legal basis sufficient to override the statutory requirement to eliminate all highwalls and restore the approximate original contour (AOC)." The OSM interpretation of highwall elimination had regressed to the limited view that the structure must be entirely backfilled and/or laid back to a very mild slope gradiant.

The decision document continues on to state: "This decision shall not be construed as preventing the creation of bluffs when necessary to restore the approximate original contour, provided such bluffs closely resemble premining features in extent and function." It was also recognized that "...there likely will be some differences between the premining and postmining topography..." based upon site specific conditions. Further, "while the general surface configuration of the land must resemble that existing prior to mining, premining features, including rock outcrops, need not be restored in precisely the same form and location or to the same extent as they formally existed."

This confusing double-talk by OSM demonstrates they have backed away from the guidance offered in their March 29, 1989 letter to LQD. They no longer accept a "steep topographic feature" constructed from a final highwall, as elimination of that highwall. In fact, on several occasions in their disapproval notification, OSM now chose to describe the Wyoming rule revision as allowing the "retention of highwall remnants". In their March 29th letter, they clearly described the construction of bluffs as constituting highwall elimination. Clearly to OSM, reclaimed areas must first and foremost meet their interpretation of AOC. To date, this interpretation has resulted in a general flattening of reclaimed slopes from pre-mine topography, and an elimination of crucial wildlife habitat features such as eroded draws, bluff/cliff features, badlands, etc. They have perpetuated the conflict which exists whereby these erosional features eliminated by mining cannot be recreated in unconsolidated backfill. Therefore, reclaimed areas are defacto creating a flatter "general surface configuration".

The only location where such features may be developed with an acceptable erosionally stability, is at the backfill/undisturbed interface; that is the final highwall. OSM's position is that while the SMCRA provisions requiring restoration of a land's premining capability as well as restoration/enhancement of wildlife values can be subjugated by that same law's "AOC" or "highwall elimination" provisions, the reverse is not acceptable. In fact, if we accept the findings in OSM's March 29th letter (that is constructed bluffs constitute highwall elimination, and they would "...restore or complement the natural topography of the area and where they would be compatible with the approved postmining land use."), then the restoration/enhancement provisions are also overridden by shortsighted, politically motivated opinions. In this specific instance, a feature which could be economically and feasibly constructed on restricted sites, and everyone seems to agree would enhance wildlife, livestock postmining land use values on Wyoming reclaimed areas, was disapproved by OSM for political reasons, based on a preception that other regions of the country may try to use this State Program revision to somehow subjugate SMCRA.

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Planning, Rehabilitation and Treatment of Disturbed Lands
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POSTMINE DRAINAGE RECONSTRUCTION AND EROSION CONTROL AT TRAPPER MINE IN NORTHWEST COLORADO

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ABSTRACT

Portions of five major drainageways and their tributaries were regraded and appropriately treated to reduce the erosion rate and assist in permanent channel stabilization at Trapper Mine (surface coal mine) in 1987, 1988, and 1989. A wide variety of erosion control materials, methods and sediment reducing measures were used in reconstructed drainageways and on adjacent sideslopes. Vegetation response, decreased flow rates and reduced gully formation were the primary factors in assessing the success of drainage reconstruction projects. Postmine herbaceous cover, above-ground primary production and woody stem density were evaluated in reconstructed drainage channels and compared to sample data from undisturbed premine drainage locations. As expected, vegetation measurements were lower in postmine drainages than in undisturbed drainages. However, considerable vegetation growth was reported in all reconstructed drainages at the conclusion of the initial growing season and during the second growing season. The mean herbaceous cover in postmine drainages was 39% compared to 71% in undisturbed sites in 1988. In 1989, canopy cover had increased to 60% in postmine drainages and decreased on undisturbed drainage segments to 69% cover. Herbaceous primary production was severely limited in 1989 due to severe drought conditions. Flow rates were significantly reduced following the establishment of water harvesting techniques. Following treatments, the estimated erosion rate was reduced 24 times the pre-treatment erosion rates.

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INTRODUCTION

Surface water runoff is the major contributor to accelerated erosion at Trapper Mine. Runoff is discharged for only brief periods as a result of snowmelt or high-intensity, short duration thunderstorms. Such events can have devastating effects on reconstructed drainageways, maintenance costs, and sediment pond cleaning costs. Thus, Trapper Mine initiated a determined effort starting in 1986 to develop techniques sufficient to control accelerated erosion of reclaimed drainage basin systems at Trapper Mine.

In the semi-arid western United States the loss of topsoil and the degradation of water quality are strongly influenced by natural fluvial processes. Langbein and Schumm (1958) showed that sediment yield varies with effective precipitation, with maximum sediment yield occurring in semi-arid regions and lesser amounts of sediment yield in both arid and humid areas. In semi-arid regions it is not uncommon to find poor soil and inadequate vegetative cover. These factors coupled with significant precipitation events are sufficient to cause accelerated erosion (Langbein and Schumm 1958, Gray and Leiser 1982).

Besides fluvial processes, geologic structure and controls may also influence the form of drainage basins and stream patterns. Drainage basins are often referred to as the basic hydrologic, geomorphic or landscape unit and take into consideration the influence of hillslopes and channels to define a drainage network (Chorley et.al. 1984, and Toy et.al. 1987). The origin and function of a drainage basin is the result of the erosion forces of flowing water and the resistive forces of the geologic materials underlying the basin. Outcrops of resistant bedrock will cause stream channels to turn abruptly or follow the outcrops of more erodible materials developing a deformed (parallel, trellis, rectangular, radical or annular) drainage pattern (Zernitz 1982, and Toy et.al. 1987). When drainages form without the influence of geologic control, a tree-like or dendritic pattern forms that is characterized by irregular branching with tributaries joining main channels at many different angles (Toy et.al. 1987). The design or extent of drainage pattern development is also dependent upon the factor, time.

In summary, the soil erosion factors which included the erosivity of the eroding agent (water and sediment), the erodibility of the soil, the slope of the land and plant cover (Morgan 1986), coupled with other fluvial processes and geologic structure all impact the development of a drainage basin system. Changes to any of these factors will influence the historic rates of drainage development and eventual drainage system expression and stability.

Surface mining and reclamation activity may remove bedrock drainage control and replace such control with unconsolidated spoil material that is relatively homogeneous in nature. Over time, the resultant drainage which develops will tend to dendritic in pattern with possible loss of natural erosion control. The fractured spoil material may produce a modification to what would naturally develop in terms of drainage pattern or hillslope and channel gradients. To compensate for this geologic change, hillslope and channel gradients could be reduced or appropriate conservation techniques (agronomic and physical) could be incorporated to reduce the potential for accelerated erosion over and above baseline erosion rates.

Agronomic measures include the use of vegetation, and soil structure improvements to control erosion and protest soil. Physical methods include some type of manipulation of the surface topography to either reduce gradients, lengthen channels or dissipate the energy of flowing water.

The objective of this project report is to describe viable conservation alternatives, such that successful drainage channel reconstruction of drastically disturbed lands may be accomplished in a cost effective manner.

STUDY AREA

Trapper Mine is a surface coal mine located approximately 6-1/2 miles south of the city of Craig, CO, along the northern slope of the Williams Fork Mountains. The climate is semi-arid steppe and is characterized by cold winters and moderately warm summers. The average annual precipitation is 13.9 inches, one-third of which falls in the form of snow and is the principal source of stream flow for the region. Soils are generally deep and formed in alluvium and colluvium derived from sandstone and shale. The topography is described as rolling hills with relativity steep slopes (average - 14%). The prevalent vegetation type is mountain shrub which interfaces with stands of big sagebrush at lower elevation and aspen types at higher elevations.

METHODS

At Trapper Mine, five major drainageways and their tributaries were regraded and appropriately treated to reduce the erosion rate and assist in permanent channel stabilization in 1987, 1988 and 1989. At the conclusion of the 1989 field season, approximately 36,450 linear feet (6.9 miles) of permanent drainageway reconstruction had been completed at Trapper Mine.

Vegetation Sampling Methods

Herbaceous plant canopy cover, annual herbaceous primary production and woody stem densities were measured on seven postmine reclaimed drainage sites and on two undisturbed premine drainage locations in 1988 and 1989. Plant canopy cover was estimated in 3,100-m transects spaced 10-m apart at each site. Herbaceous plant canopy cover and percent mulch cover were estimated by species using the point-hit technique (Optical Point Bar) (Viert 1985). Herbaceous production was estimated by clipping 6,1/4-m plots (20-m spacing) on each of the three line transects at each site. Woody stem density on undisturbed drainage segments was calculated using the point-center-quarter (PCQ) method (Dix 1961). Five PCQ's were conducted on each line transect at 20-m spacing. Distances from the center of each PCQ to the nearest live stem in each quarter was recorded. Woody stem densities in reconstructed drainage segments are an approximation of the actual seedlings planted at each site.

Erosion Control Methods

A wide variety of soil erosion control materials, methods and sediment reducing measures were used in reconstructed drainageways, on reclaim sideslopes and on regraded spoils. The following list of measures and/or materials were applied in combination to decrease the likelihood of accelerated erosion, to reduce flow rates and to reduce the sediment loading in downstream sedimentation structures.

Dozer basins (sediment basin) were constructed to trap and store sediment on newly stripped topsoil areas and on regraded spoils to reduce or abate the sediment load. Basins are used to prevent the siltation of diversions, waterways, livestock ponds, and streams; to trap sediment originating from the active mine site and to prevent undesirable deposition on undisturbed bottomlands and reclaimed areas. The dozer basins primary use is to trap sediment, reduce on-site erosion, reduce peak flows at downstream locations, and reduce gully erosion.

Livestock watering tanks (ponds) are used to trap water on reclaimed sideslopes, in drainageways, and to reduce peak flows at downstream locations making available reliable water for wildlife use. The location of livestock ponds is such that a minimal amount of sediment will be deposited. This was accomplished by installation of ponds at headwater locations or on relatively gentle grades often within water harvesting diversions on reclaim sideslopes.

Water harvesting diversions are channels constructed across slopes with a supporting ridge on the lower side that is used to transport excess water from areas that need protection to sites where water can be used or disposed of safely. A diversion's effectiveness as a sediment reducing measure is in diverting the runoff which would otherwise flow across erosion susceptible areas, thus detaching and transporting soil particles.

Contour farming and live haul topsoil transport are used on all reclaimed sideslopes and drainage areas when possible. Topsoil replacement, seedbed preparation, and planting are done on the contour. Contouring can reduce erosion by 40 to 50 percent. When contour farming is combined with live material topsoil transport the erosion loss potential can be further reduced. Contouring provides excellent erosion control by reducing transport from moderate rainfall events. Contouring in combination with diversion establishment can be very effective in reducing erosion potential.

Rock check structures are used to dissipate the energy of flowing water within the drainageway channel. Debris and sediment tend to be deposited and trapped upstream of structures. This in turn permits establishment of vegetation behind structures which further stabilize the channel. In addition, filter fabric is installed and used to line rock check structure core trenches, thus providing additional structural support and reduces the potential for advancement of downstream headcutting to move upstream.

Cover crops and mulch are used very effectively in drainageways to reduce the detachment of soil by rainfall and runoff while providing seasonal protection and soil improvement. Cover crops provide protection from wind and water erosion during vegetation establishment periods when permanent vegetation is inadequate to provide adequate cover.

Permanent vegetative (grasses, forbs and shrubs) cover provides the most significant and permanent long term solution to erosion control problems. The selection of species adapted to the climate and soils is one of the most important steps in achieving success. Woody plants are desirable for the long term stability of a particular site. However, woody plants require time to develop sufficient size to control erosion adequately and the quick cover that can be obtained with grasses and forbs is needed in the interim. The principles for selection of herbaceous vegetation is based on a particular species adaptation to the mine site and its erosion control potential. The ideal species have strong root development. A diverse mixture of plant species increases the assurance of a stand as it is difficult to anticipate all of the variables that will affect germination and stand establishment on any given site.

Willow wattles and woody seedling transplants are installed in drainageways and serve as energy dissipaters for water and soil moving down the drainageway and provide long term stability. Woody plants filter and trap entrained debris (soil, small rocks, veg litter) and provide a series of areas with reduced slope angles on which vegetation can be established. Deep rooted woody vegetation prevents gully formation and will become part of the permanent stabilizing cover.

Brush matting (crimping) is essentially a deep mulch of hardwood brush and soil crimped into existing drainage cuts. The technique is employed very effectively in damaged stream channels and on stream banks to protect against accelerated erosion rates when a channel needs repair.

Geotextiles, erosion blankets and other erosion control fabrics, are used effectively in reducing stream velocities and increasing sedimentation in drainageways. A variety of materials are used at Trapper Mine and include geoweb - a soil confinement system, C125 coconut blanket , landglas erosion control fibers (landglas is tacked with CSS-1 emulsified asphalt), fibron fibers, mirifi erosion cloth, jute erosion netting and miramat blankets.

RESULTS

Vegetation response, decreased flow rates and reduced gully formation were the primary factors in assessing the success of drainage reconstruction projects at Trapper Mine.

Postmine herbaceous canopy cover, herbaceous production, and woody stem density were evaluated in reconstructed drainage areas in 1988 and 1989 and compared to sample data from undisturbed premine drainage areas. (Sampling was conducted on drainageways reconstructed in 1987.) Various postmine drainage treatments were incorporated to evaluate vegetation response on topsoiled, non-topsoiled, irrigated, and non-irrigated drainage segments (Table 1). Treatments on undisturbed areas were irrigated and non-irrigated drainage segments (Table 1). Generally, vegetation measurements were lower in reconstructed drainageways than in undisturbed drainage sites. This is understandable due to the short duration of vegetation re-establishment. However, considerable vegetation growth was reported in all reconstructed drainages after the initial growing season and during the second growing season.

Vegetation response was the best on topsoiled and irrigated treatments and was significantly higher when comparing topsoiled versus non-topsoiled areas without irrigation. The overall herbaceous canopy cover for all reconstructed drainage treatments in 1988 (measure of initial growing season) was 39% compared to 71% on undisturbed drainage segments. In 1989, herbaceous canopy cover had increased to 60% in reconstructed drainages and decreased on undisturbed drainage segments to 69% cover.

Herbaceous primary production averaged 876 lbs/acre in reconstructed drainages and 1943 lbs/acre on undisturbed sites in 1988. In 1989, herbaceous primary production decreased to 420 lbs/acres on reconstructed drainages and 521 lbs/acre on undisturbed drainage segments. The reduction in production in 1989 compared to 1988 was a result of severe drought conditions in the area during 1989.

Table 1. Vegetation cover, production and woody stem densities on disturbed (postmine) and undisturbed drainages at Trapper Mine in 1988 and 1989.

	Herbaceous Canopy Cover (%)				Herbaceous Production (lbs/acre)				Woody Stem Density (stems/acre)			
Reconstructed Drainage (1)(2)	Irrigated(3)		Non-Irrigated		Irrigated		Non-Irrigated		Irrigated		Non-Irrigated	
	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989
Upper Coyote (topsoiled)			32	61			246	466			314	628
Middle Coyote (topsoiled)			46	74			1003	583			314	628
Lower Coyote (topsoiled)	51	79			1835	1069			628	1256		
Upper West No Name (topsoiled)	36			53	725			168	628			1256
Lower West No Name (topsoiled)	50			67	1687			176	628			1256
Upper East No Name (not topsoiled)			24	44			210	240			314	628
Lower East No Name (not topsoiled)	33			40	426			236	628			628
Undisturbed Drainage(4)												
Upper Flume			63	(5)			694	(6)			7223	
Lower Flume	80	69			3191	521			2552			

(1) Drainageways regraded, topsoiled and drill seeded in late summer 1987.

(2) Woody stem density comprised of Amelanchier alnifolia (Saskatoon Serviceberry), Crataegus spp (Hawthorn), Populus angustifolia (Narrowleaf Cottonwood) Prunus americana (American Plum), Prunus virginiana (Common Chokecherry), Ribes aureum (Golden Current), Rosa woodsii (Wood's Rose), Salix vitalina (Golden Willow), and Symphoricarpus oreophilus (Mountain Snowberry).

(3) Drainage segments irrigated in 1988 may not have been in 1989 due to pit dewatering activity or drying of natural springs.

(4) Woody stem density comprised of Amelanchier alnifolia (Saskatoon Serviceberry), Artemisia cana (Silver Sagebrush), Artemisia tridentata (Big Sagebrush), Chrysathamnus viscidiflorus (Low Rabbitbrush), Prunus virginiana (Common Chokecherry), Quercus gambelii (Gambel Oak), Rosa Woodsii (Wood's Rose), Symphoricarpus oreophilus (Mountain Snowberry).

(5) Samples not taken as area was severely impacted by drought and livestock grazing.

(6) Samples not taken as area was severely impacted by drought and livestock grazing.

Woody stem densities on undisturbed drainage areas averaged 4888 stems/acres for both years compared to 471 stems/acre in 1988 and 897 stems/acre in 1989 on reconstructed drainage areas.

Flow rates have been significantly reduced following the installation of stock tanks and dozer basins on reclaim and spoil areas, respectively. Discharge readings were recorded from a 10-year, 24-hour parshall flume (with Stevens Water Level Recorder) located in the north end of the Coyote Gulch reconstructed drainage channel. The peak flow in 1987 (22.24 cfs) occurred as a result of a high intensity thunderstorm in June (.74" ppt) and caused severe erosion within the newly regraded drainage channel. In 1988, following drainage reconstruction and water retention strategies, the peak flow rate associated with a .53" precipitation event (June) registered .04 cfs of discharge water. Similarly, a high intensity thunderstorm in July 1989 (.75" ppt) resulted in a discharge of 1.23 cfs. In addition to assisting in runoff control, the proper frequency and distribution of livestock ponds has aided in evenly spreading big game animal use over the entire reclaimed area, thus reducing their impact on vegetation establishment.

Gully formation and sediment loss was reduced significantly in postmine drainageways when compared to pre-drainage reconstruction. In Coyote Gulch, for example, an estimated 99,400 cubic yards of sediment was lost to gully erosion and sheet and rill erosion from 1984-1987. Following treatment an estimated 1,360 cu yds of sediment is lost annually to sheet, rill and gully erosion. This is a reduction in the annual erosion rate of 24 times the pre-treatment erosion rates. Much of the success for the reduction in erosion rates must be attributed to the wide variety of erosion control materials, methods and sediment reducing measures that were used in reconstructing drainageways and adjacent reclaimed sideslopes.

As a result of appropriate erosion control treatment in re-established postmine drainageways, Trapper Mine has not needed to clean a single sediment pond in two years. A net savings to Trapper Mine of $50,000 has been realized since drainage reconstruction was initiated and sedimentation pond cleaning ceased.

CONCLUSIONS

As a strategy for soil conservation planning, the promotion of vegetation in combination with natural and/or artificial erosion control measures, has much to offer. Vegetation is one factor that can be easily manipulated by careful management. Beyond that, better vegetative growth, by selecting plants that are well adapted to a particular climate or soil, will almost always provide direct economic benefits in terms of vegetation production, stability and reduced soil loss.

The proper implementation of erosion control materials and sediment reducing measures on reclaimed sideslopes, drainageways, and on regraded spoils are valuable in reducing peak water flows and sediment loads into drainages. Dozer basins are useful to trap and store sediment on newly stripped topsoil areas and on regraded spoils. Livestock water tanks are valuable as they trap water on reclaimed sideslopes, in drainageways, and reduce peak rates of flow at downstream locations, making available reliable water for wildlife and livestock use. Water harvesting diversions constructed across slopes are important to transport excessive water from areas that need protection to sites where water can be used or disposed of safely. Contour farming is essential to reduce sheet and rill erosion on reclaimed sideslope. When combined with live haul topsoil transport the erosion potential is further reduced. The installation of rock check structure to dissipate the energy of flowing water and trap sediment and debris is valuable in stabilizing channels and promoting vegetation growth. Finally, the use of geotextiles, erosion blankets and other erosion control fabrics are effective in reducing stream velocities and increasing sedimentation in drainageways.

The combination of appropriate conservation measures and an aggressive repair program add up to successful treatment of reconstructed drainage channels and consequently successful reclamation at Trapper Mine while permanent vegetation establishes.

Perhaps the major problem with such a soil conservation strategy is that it requires continuous, sensitive, timely and knowledgeable management of the soil and vegetation and the use of appropriate and cost effective erosion control techniques and material to be fully effective. But the rewards in terms of reduced soil loss and potential dollar savings are indisputable. One must keep in mind, however, that regardless of soil conservation planning and implementation efforts to stabilize post mine drainageways, their long term stability and that of adjacent undisturbed drainages is subject to the affects of catastrophic weather patterns.

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A GEOMORPHIC THRESHOLD FOR VALLEY-FLOOR EROSION IN RECLAIMED SURFACE-MINED DRAINAGE BASINS, NORTHWESTERN COLORADO

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ABSTRACT

Surface-coal mining and reclamation in northwestern Colorado has caused substantial changes in geology, pedology, vegetation, hydrology, and geomorphology of many drainage basins. These changes have increased the potential for gully erosion on reclaimed valley floors. Gullies on some reclaimed valley floors may be affected by geomorphic variables that can be manipulated during reclamation. Valley-floor erosion in several reclaimed drainage basins is related to three geomorphic variables: drainage area, valley gradient, and valley-floor width. The product of drainage area and valley gradient defines the area-gradient index. Unstable valley floors were associated with larger area-gradient indicies than were stable valley floors. Clustering of data from stable and unstable valley-floor reaches and the relation between valley-floor width and the area-gradient index defined the valley-erosion threshold. Reclaimed valley floors that had valley-floor width less than the threshold were more likely to be gullied than valley floors that had widths greater than the threshold. Geomorphic thresholds may be useful as planning tools in future reclamation projects.

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INTRODUCTION

A potential for gully erosion of topsoil and spoil material exists at reclaimed surface-coal mines. Water flowing through gullies on reclaimed valley floors may mobilize topsoil and spoil material, increase downstream sedimentation rates, affect downstream water quality, and propagate rill and gully erosion upstream to nearby hillslopes and tributaries. Gully erosion occurs when the erosive forces (stream power) on a valley floor exceed the resistant forces (material strength, critical particle size, and sediment supply). Surface mining and reclamation cause changes that tend to decrease resistant forces; however, some recurrent valley-floor gullying may be caused or exacerbated by an imbalance of geomorphic conditions that tend to increase erosive forces.

The geomorphology of a reclaimed surface-mined drainage basin has a considerable effect on the configuration and character of the new drainage network and on the stability of stream channels. Creation of an appropriate valley morphology is critical to the establishment of stable streams in reclaimed surface-mined areas. Valleys are topographic areas where soil water and surface water collect and where stream channels often form. The stability of the valley floor and, hence, the stability of the stream channel, is determined partly by the contributing drainage area and by the valley morphology. The objective of this paper is to identify geomorphic relations associated with valley-floor instability in reclaimed surface-mined drainage basins in northwestern Colorado. These geomorphic relations may be useful as planning tools in future reclamation projects.

SURFACE MINING AND RECLAMATION IN NORTHWESTERN COLORADO

Coal extraction at some of the larger surface-coal mines in northwestern Colorado has disrupted entire drainage basins. Many of these drainage basins have been reclaimed for several years but currently have gullied valley floors. Surface mining alters many geologic, pedologic, hydrologic, vegetative, and geomorphic conditions that control erosion. The premining lithology and structure are replaced by unconsolidated spoil material that has a decreased resistance to erosion. Mechanical compaction of spoil and topsoil and replacement of native woody vegetation by grasses tend to produce greater surface runoff (Younos and Shanholtz, 1980; Golding and Swanson, 1986; Trimble, and others, 1987). Irregularities in the reconstructed geomorphology, such as steep hillslope segments or constricted valley reaches, increase the erosiveness of surface flow. Changes in spoil-material and topsoil physical properties and changes in vegetation type are inevitable consequences of surface mining; however, the potential for some erosion might be decreased by creating a reclaimed land surface where unstable morphologies are eliminated (Stiller and others, 1980).

Valley-floor stability was studied in 10 reclaimed drainage basins at 4 surface-coal mines in northwestern Colorado: the Trapper, Hayden Gulch, Seneca II, and CYCC Mines[1]. Data from 27 valley-floor reaches in these reclaimed drainage basins were collected (Table 1). Data from seven unmined valley-floor reaches in nearby unmined drainage basins were included in the study for comparison. The unmined drainage basins had elevations, orientations, and drainage areas similar to most of the reclaimed drainage basins in the study.

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[1] The use of industry or firm names in this paper is for location purposes only and does not impute responsibility for any present or potential effects on the natural resources.

TABLE 1. Geomorphic data from surveys of selected valley-floor reaches in reclaimed and unmined drainage basins

[Rec, reclaimed; Unm, unmined; St, stable; Us, unstable; He, healing; ft/ft, feet per foot; ft, feet]

Site code	Land-use code	Stability code	Mine	Drainage basin name	Contributing drainage area (acres)	Valley gradient (ft/ft)	Valley-floor width (ft)	Area-gradient index (acres)	Valley-erosion index (acre/ft)
EBZ-3	Rec	St	Trapper	East Buzzard Gulch	12.8	0.228	40	2.9	0.86
EBZ-1	Rec	Us	Trapper	East Buzzard Gulch	20.5	.164	28	3.4	1.3
EBZ-4	Rec	St	Trapper	East Buzzard Gulch	80.6	.108	46	8.7	.92
EBZ-5	Rec	Us	Trapper	East Buzzard Gulch	96.0	.131	45	12.6	1.0
EBZ-7	Rec	St	Trapper	East Buzzard Gulch	186	.0355	46	6.6	.87
EBZ-9	Rec	Us	Trapper	East Buzzard Gulch	320	.0303	40	9.7	1.1
COY-1	Rec	St	Trapper	Coyote Gulch	5.76	.0819	38	.47	.64
COY-2	Rec	St	Trapper	Coyote Gulch	8.96	.160	56	1.4	.53
COY-4	Rec	Us	Trapper	Coyote Gulch	55.7	.148	33	8.2	1.3
P20-1	Rec	St	Hayden Gulch	Basin P20	11.5	.0309	30	.36	.77
P20-2	Rec	Us	Hayden Gulch	Basin P20	13.4	.0672	27	.90	1.0
P20-3	Rec	Us	Hayden Gulch	Basin P20	15.4	.0904	26	1.4	1.1
P30-1	Rec	St	Hayden Gulch	Basin P30	10.9	.0561	32	.61	.80
P30-2	Rec	St	Hayden Gulch	Basin P30	15.4	.0502	65	.77	.41
S60-5	Rec	Us	Seneca II	Basin S60	65.9	.180	55	11.9	.81
S70-5	Rec	St	Seneca II	Basin S70	37.8	.0172	45	.65	.57
S70-6	Rec	Us	Seneca II	Basin S70	38.4	.218	35	8.4	1.2
311-1	Rec	St	CYCC	Basin 31-1	11.5	.102	20	1.2	1.4
311-3	Rec	Us	CYCC	Basin 31-1	33.9	.156	20	5.3	1.9
311-7	Rec	Us	CYCC	Basin 31-1	88.3	.0988	36	8.7	1.2
311-7a	Rec	St	CYCC	Basin 31-1	88.3	.0249	36	2.2	.90
311-9	Rec	Us	CYCC	Basin 31-1	117	.169	37	19.8	1.3
312-5	Rec	Us	CYCC	Basin 31-2	51.8	.101	36	5.2	1.1
312-7	Rec	St	CYCC	Basin 31-2	64.6	.0599	48	3.9	.76
071-7	Rec	St	CYCC	Basin 7-1	45.4	.0319	30	1.4	.99
071-9	Rec	Us	CYCC	Basin 7-1	48.0	.138	23	6.6	1.7
072-9	Rec	Us	CYCC	Basin 7-2	41.6	.0758	34	3.2	1.0
EBZ-2	Unm	St	Trapper	East Buzzard Gulch	31.4	.179	51	5.6	.76
ENN-1	Unm	St	Trapper	East No Name Gulch	90.2	.125	57	11.3	.78
DGT-1	Unm	St	Hayden Gulch	Dowden Gulch Tributary	12.2	.0868	56	1.1	.51
DGT-2	Unm	St	Hayden Gulch	Dowden Gulch Tributary	33.9	.161	36	5.5	1.0
S20-9	Unm	St	Seneca II	Basin S20	28.8	.127	45	3.7	.80
S40-8	Unm	He	Seneca II	Basin S40	12.8	.107	22	1.4	1.4
S90-9	Unm	He	Seneca II	Basin S90	22.4	.0686	18	1.5	1.7

Reclaimed drainage basins in the study area had drainage-basin areas that ranged from 17.9 to 320 acres, and all drainage basins were drained by first- or second-order drainage networks (Strahler, 1957, p. 914). Soil in the reclaimed drainage basins was disturbed by removal from the original location, by storage in stockpiles, and by reapplication by heavy machinery. These activities tended to homogenize the composition, increase bulk density, decrease porosity, and decrease infiltration rate of the topsoil. Vegetation in reclaimed drainage basins was almost entirely perennial grasses and forbs. Attempts have been made to transplant or seed woody species in reclaimed areas, but these species were a negligible percentage of the existing vegetation cover. The valleys of reclaimed drainage basins had no bedrock control and were reconstructed from the replaced, pulverized spoil material. The cross sections of many of these reclaimed valleys often were narrow and v-shaped, depending on the profile of the adjacent, reclaimed valley-side hillslopes.

Unmined drainage basins in the study area had drainage-basin areas that ranged from 13.4 to 195 acres, and all drainage basins had first- or second-order drainage networks. Soil and vegetation in the unmined drainage basins varied with elevation, geologic parent material, and microclimate. Soil types were predominantly deep, well-drained loams, or silty clay loams that had minor quantities of clay loam, sandy clay loam, and gravelly loam. Rock outcrops and colluvial deposits comprise a small percentage of the unmined land in the study area. Vegetation types included aspen, mountain shrub, big sagebrush, and grassland communities. The valleys of unmined drainage basins generally were parabolic in cross section. Many of these valleys were formed on geologic dip slopes, but several valleys intersected dipping sedimentary outcrops.

METHODS OF DATA COLLECTION

Geomorphic characteristics for each drainage basin and valley-floor reach were obtained from field surveys and topographic maps. Longitudinal and transverse valley-floor surveys were made onsite to determine valley gradient, valley-floor width, and channel dimensions. Valley gradient was computed over a distance of about 200 feet from a longitudinal survey. Valley-floor width, the horizontal distance between the lateral limits of the valley floor, was estimated onsite and confirmed from a plot of the transverse valley-floor profile. The lateral limits of the valley floor were identified as the noticeable flattening of the toe of the adjacent valley-side hillslopes. Identification of valley-floor limits was somewhat subjective in several reclaimed valleys because of topographic irregularities caused by spoil-material handling. The surveyed reaches were located on topographic maps, and the contributing drainage areas were determined for each valley-floor reach with a digital planimeter.

Reclaimed valley-floor reaches were classified as stable or unstable, depending on the geomorphic condition of the stream channel or gully on the valley floor. Stable reclaimed valley-floor reaches had channels characterized by sloping, vegetated banks, large width-to-depth ratios, and relatively fine sediment in the channel bed and banks. Five stable reclaimed valley-floor reaches that had relatively small contributing drainage areas (less than about 13 acres) had no developed channels. Unstable reclaimed valley-floor reaches had degraded, gullied channels that were characterized by steep banks devoid of vegetation, small width-to-depth ratios, and coarse spoil material exposed in the channel bed and banks.

Most unmined valley-floor reaches in the study area were classified as stable because the stream channels were not degraded or actively eroding their valley floors. Two unmined valley-floor reaches had evidence of past gullies; however, at the time of the study (1987), the channels were healing.

ANALYSIS OF DATA

Mine companies have reconstructed drainage basins, valleys, and drainage networks; however, the morphology of some reclaimed drainage basins and valleys seems to have been determined by spoil-material handling considerations. In most reclaimed drainage basins, stream channels were allowed to develop naturally on the recontoured surfaces, but some channels were established during reclamation. The drainage area, drainage density, and drainage-network order of many reclaimed drainage basins have been altered noticeably from the pre-mining conditions. Changes also have occurred in the distribution of land mass within individual basins.

Valley gradient, G_v, sometimes referred to as valley slope, is a geomorphic variable that has a substantial effect on the erosion potential of a valley-floor (Patton and Schumm, 1975). Reclaimed G_v's generally were within the range of pre-mining G_v's for most drainage basins in the study area. However, on a reach-by-reach basis, some reclaimed G_v's were substantially different from the pre-mining G_v's. Longitudinal profile convexities in the lower part of some reclaimed drainage basins resulted from spoil handling and a redistribution of land mass in the drainage basin. Subtle changes in reclaimed valley-floor profile and local G_v may have increased the erosion potential of some valley-floor reaches, especially where the contributing drainage area was large.

The relation between valley gradient, G_v, and drainage area, A_d, for 27 reclaimed valley-floor reaches and 7 unmined valley-floor reaches is shown in Figure 1. The variability in the relation between G_v and A_d was large, and there was little correlation between these two geomorphic variables. Some of the variability in the data from reclaimed valley-floor reaches was accounted for when the data were categorized on the basis of valley-floor stability; data from the unstable reaches tended to be clustered in the upper part of the plot. All of the reclaimed valley-floor reaches that had drainage areas less than about 13 acres seemed to be stable. By comparison, many reclaimed valley-floor reaches that had drainage areas greater than about 13 acres were unstable, if they also had relatively steep G_v (greater than about 0.06 ft/ft).

Data from unmined valley-floor reaches are included in Figure 1 for comparison. It was assumed that geomorphic conditions in the nearby unmined drainage basins are representative of geomorphic conditions that existed before mining in what are now the reclaimed drainage basins. Data from the unstable reclaimed valley-floor reaches plot with data from the unmined valley-floor reaches. The data from stable reclaimed reaches have smaller values of G_v for similar A_d compared to data from the unmined reaches. Although the values of G_v and A_d of many reclaimed valley-floor reaches are similar to the values of G_v and A_d of unmined reaches (Figure 1), many of these reclaimed valley-floor reaches may be less stable than the nearby unmined valley-floor reaches.

Begin and Schumm (1979) studied gully erosion and instability of alluvial valley floors. They investigated the effect of drainage area, A_d, and valley gradient, G_v, on the average shear stress exerted by flow on the valley floor. Average shear stress, τ_o, is the tractive force per unit surface area, and is a function of: the unit weight of water, γ; the hydraulic radius of flow, R; and the energy gradient, or slope, S (DuBoys, 1879):

$$\tau_o = \gamma R S. \tag{1}$$

S can be approximated by the valley gradient, G_v, when sinuosity is low. For wide, shallow flows, which may occur on an initially ungullied valley floor, R can be approximated by flow depth, D. Therefore, the equation for τ_o can be approximated by:

$$\tau_o = \gamma D G_v. \tag{2}$$

The cross-sectional area, flow width, flow depth, and flow velocity have been empirically related to discharge, Q, in many hydraulic geometry studies (Leopold and others, 1964). Similarly, Q has been related to drainage-basin characteristics, most commonly to drainage area, A_d, in many regional studies. By using these empirical relations, Begin and Schumm (1979) proposed that the average shear stress, τ_o, acting on a valley floor could be related to A_d and valley gradient, G_v, by a shear-stress indicator, τ_i:

$$\tau_i = c\ A_d^{\ k}\ G_v, \tag{3}$$

where coefficients c and k are determined by the relations between D and Q, and between Q and A_d. The average shear stress, τ_o, becomes the shear-stress indicator, τ_i, because many assumptions were made about the relations between hydraulic and geomorphic variables. Begin and Schumm (1979) suggested that the range of k in Equation 3 was about 0.2 to about 0.4, based on empirically determined exponents for hydraulic geometry and the relation between Q and A_d. Because of the small value of k, τ_i is much more sensitive to changes in G_v than to changes in A_d.

The general effect of drainage area, A_d, and valley gradient, G_v, on valley-floor stability can be represented by the area-gradient index, AGI. AGI is the product of A_d and G_v, and is not dependent on empirically determined coefficients and exponents. The units of AGI are the units of A_d--in this paper, acres.

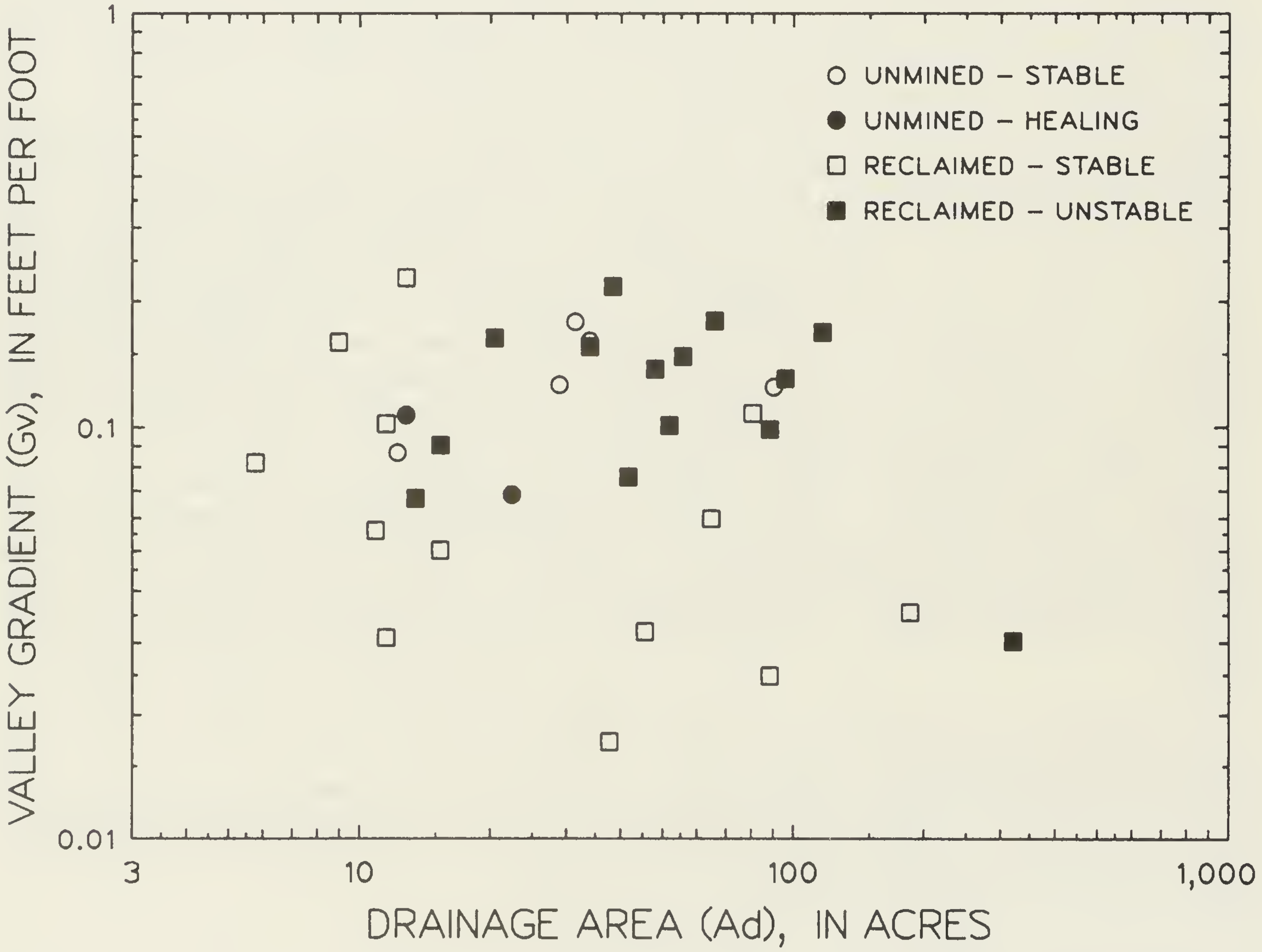

FIGURE 1. Valley gradient compared to drainage area from surveyed valley-floor reaches.

The graph of valley gradient, G_v, and drainage area, A_d, for surveyed valley-floor reaches shows considerable overlap of data from the reclaimed-stable and reclaimed-unstable groups (Fig. 1). However, a t-test of group means indicated there was a significant difference between the area-gradient index, AGI, of stable reclaimed valley-floor reaches and unstable reclaimed valley-floor reaches ($P = 0.0034$, 95-percent level). The mean AGI of stable reclaimed reaches was 2.4 acres, and the mean AGI of unstable reclaimed reaches was 7.5 acres. The lower limit of AGI for unstable valley-floor reaches is about 1 acre, and the upper limit of AGI for stable valley-floor reaches is about 10 acres.

Valley-floor width is another geomorphic variable that affects the initiation of gully erosion on reclaimed valley floors. The valley floor in a small drainage basin is an area where unsaturated-zone water and surface runoff from the adjacent hillslopes collect. A narrow valley floor will tend to concentrate soil water and surface runoff, which increases flow velocity, stream power, and the probability of some type of erosion.

Valley-floor morphology in a naturally evolving drainage basin primarily is determined by hillslope processes that act on nearby valley-side hillslopes, and by fluvial processes that act on the valley floor. Valley-floor width, W_v, often is related to drainage area, A_d. W_v of reclaimed drainage basins in the study ranged from about 20 to 65 ft (Table 1), but W_v was uncorrelated with A_d. The valley-floor morphology in reclaimed drainage basins was determined by spoil-material handling rather than by hillslope and fluvial processes. Many unstable reclaimed valley-floor reaches had narrower W_v for a specific A_d than did stable valley-floor reaches, but t-tests of the mean of W_v indicated that the difference between the reclaimed stable reaches and reclaimed unstable reaches was not statistically significant (95-percent level).

VALLEY-EROSION THRESHOLD

The relation between valley-floor width, W_v, and area-gradient index, AGI, is shown in Figure 2 for 13 stable reclaimed valley-floor reaches, 14 unstable reclaimed valley-floor reaches, and 7 unmined valley-floor reaches. There are no obvious linear relations between W_v and AGI, but there are apparent data clusters from the stable reclaimed and unstable reclaimed reaches. Data from stable reclaimed reaches tend to plot in the upper and left parts of the graph, whereas data from unstable reclaimed reaches tend to plot in the lower and right parts of the graph. Data from the two reclaimed groups overlap slightly, but much less than when valley gradient, G_v, was plotted against drainage area, A_d, (Fig. 1). Data from three of the stable unmined valley-floor reaches plot with data from stable reclaimed reaches (Fig. 2).

Clustering of valley-floor width, W_v, and area-gradient index, AGI, data may define a threshold zone between stable and unstable reclaimed valley floors for different combinations of W_v and AGI. A t-test of group means indicated that there was no significant difference between W_v of stable reclaimed valley-floor reaches and unstable reclaimed valley-floor reaches ($P = 0.10$, 95-percent level); however, an analysis of covariance indicated there was a significant difference in the relation of W_v and AGI between stable and unstable reclaimed valley-floor reaches. Stable reclaimed valley-floor reaches tend to have wider W_v than unstable reclaimed valley-floor reaches for the same AGI (Fig. 2).

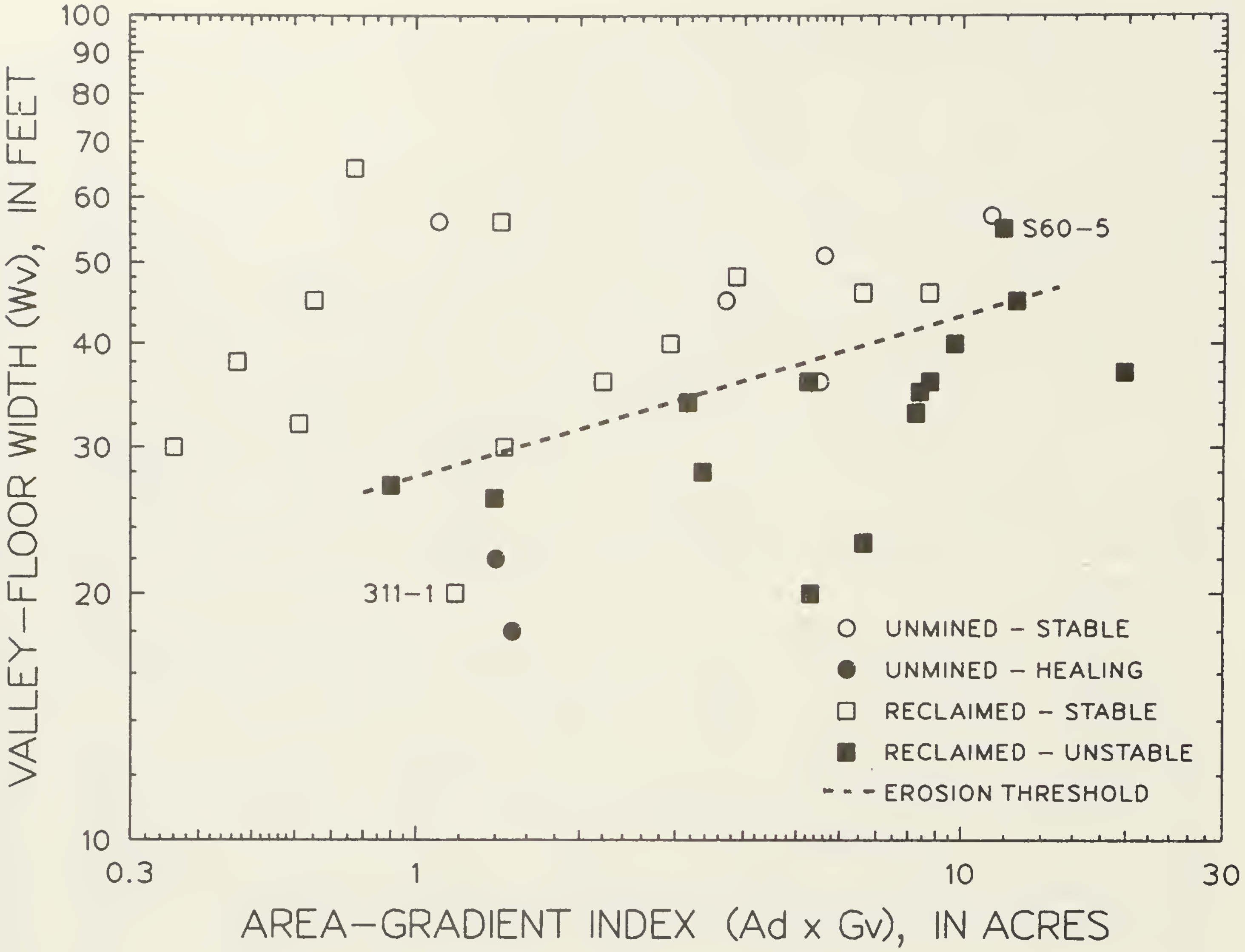

FIGURE 2. Valley-floor width compared to area-gradient index from surveyed valley-floor reaches.

A line was drawn on Figure 2 that separated most of the stable reclaimed valley-floor reaches from most of the unstable reclaimed valley floor reaches. Valley-floor reaches that plot above the line tend to be stable, whereas reaches that plot below the line tend to be unstable. This line represents the valley-erosion threshold for reclaimed drainage basins in the study area, and is represented mathematically as:

$$W_v = 28\ AGI^{0.19}. \qquad (4)$$

The valley-erosion threshold was graphically fitted and does not represent a statistically defined discriminant-function line.

Two reclaimed valley-floor reaches do not plot with groups delineated by the valley-erosion threshold. Site 311-1 (AGI=1.2, W_v=20) was classified as stable, but it plots with unstable valley-floor reaches (Fig. 2). The valley floor at this site had several large, discontinuous rills, but no gully or incised channel. It is possible that the valley floor at site 311-1 was unstable, but that the criterion used to classify unstable sites (presence of a gully) had not yet developed. Site S60-5 (AGI=11.9, W_v=55) was classified as unstable, but it plots with stable valley-floor reaches (Fig. 2). When this site was surveyed in 1987, the channel was incised, apparently because runoff was confined to an area of the valley floor established by mechanical channelization. Onsite inspection in 1988 indicated that the channel may be stabilizing.

The shear-stress indicator, τ_i, which is a surrogate for average shear stress, τ_o, was used to account for the effects of drainage area, A_d, and valley gradient, G_v, on valley-floor erosion (Eq. 3). When a third geomorphic variable, valley-floor width, W_v, is included in the analysis, τ_i can be modified, and a geomorphic index of potential stream power can be computed (Bradley, 1980; Schumm and others, 1980).

Stream power, ω, is the force per unit area multiplied by the mean flow velocity, and can be defined as:

$$\omega = \tau_o\ u, \tag{5}$$

where τ_o is average shear stress, and u is mean flow velocity. Average shear stress, τ_o, is approximated by Equation 2. When Equation 2 is substituted for τ_o, Equation 5 can be rewritten as:

$$\omega = \gamma\ D\ G_v\ u, \tag{6}$$

where γ is the unit weight of water, 1.0; D is flow depth; and G_v is the valley gradient. From the continuity equation, mean flow velocity, u, is defined as:

$$u = \frac{Q}{W\ D}, \tag{7}$$

where Q is discharge; W is width of flow; and D is depth of flow. If this definition of u is substituted into equation 6, D cancels and ω becomes:

$$\omega = G_v\ Q\ W^{-1}. \tag{8}$$

Regional studies have related discharge, Q, to drainage area, A_d, by power functions. When Q is represented by a power function of A_d, a geomorphic index of potential stream power, ω_i, can be approximated by:

$$\omega_i = c\ G_v\ A_d^{\ k}\ W^{-1}; \tag{9}$$

where c and k are coefficients determined by the relation between Q and A_d.

A valley-erosion index, VEI, can be derived from Equation 9 by substituting the area-gradient index, AGI, for drainage area, A_d, and valley gradient, G_v, and by substituting valley-floor width, W_v, for width of flow, W:

$$VEI = c'\ AGI^j\ \ W_v^{\ -1}; \tag{10}$$

where c' and j are coefficients determined by the the relations between G_v, A_d, and AGI, and between Q and A_d.

The valley-erosion threshold (Eq. 4) was defined by the relation between valley-floor width, W_v, and the area-gradient index, AGI. Substituting the coefficients from Equation 4 into Equation 10 defines the threshold value of the valley-erosion index, VEI_t:

$$VEI_t = 28\ AGI^{0.19}\ W_v^{\ -1}. \tag{11}$$

The value of VEI_t equals 1.0.

EROSION POTENTIAL OF RECLAIMED VALLEY FLOORS

Stable valley-floor reaches that plot near the valley-erosion threshold (Fig. 2) may be potentially unstable and could become unstable and gullied if, for example, annual runoff increased substantially during a climatic fluctuation, or if a land-use disturbance on the valley floor initiated channel incision. Conversely, unstable reaches that plot near the valley-erosion threshold could begin to stabilize if, for example, annual runoff decreased as vegetation cover in the drainage basin matured and evapotranspiration increased.

The erosion potential of the reclaimed valley-floor reaches in this study can be quantified based on the distance of each point from the valley-erosion threshold. The valley-erosion index, VEI, is calculated for each valley-floor reach by using the reach AGI and W_v (Table 1), and the coefficient and exponents of VEI_t (Eq. 11). Because VEI_t=1.0, VEI calculated for a specific valley-floor reach gives a quantitative assessment of valley-floor instability (or erosion potential) relative to the valley-erosion threshold. The distance a point plots from the threshold line is described in terms of the VEI.

Lines of constant relative valley-erosion index, VEI, are superimposed on the plot of valley-floor width, W_v, and area-gradient index, AGI (Fig. 3). Most of the unstable valley-floor reaches have VEI from 1.0 to about 1.3 times the value of the valley-erosion threshold. However, for two unstable reaches, the VEI is almost twice as large as the threshold. Most of the stable reclaimed valley-floor reaches and most of the unmined valley-floor reaches have VEI from about 0.7 to 1.0 times the value of the valley-erosion threshold.

Determination of valley-erosion indices enables a quantitative assessment of the erosion potential of reclaimed valley floors when three geomorphic variables are known. However, these indices are based on geomorphic variables and can give only a simplistic approximation of the hydraulic conditions that affect erosion and valley-floor stability. Additionally, the valley-erosion index for an individual reach is dependent on the slope and intercept of the valley-erosion threshold (Eq. 4). The slope, intercept, linearity, and limits of the valley-erosion threshold were empirically determined by the distribution of stable and unstable data plotted in Fig. 2. Inclusion of new data from other reclaimed valley-floor reaches could change the position of the valley-erosion threshold. Also, the valley-erosion threshold may shift with time as the stability of the studied reaches changes in response to evolving hydrologic and geomorphic conditions. Therefore, Equation 4 needs to be considered as defining a zone or an approximation of the threshold between stable and unstable reclaimed valley-floor reaches observed in the study area.

SUMMARY

Instability of reclaimed valley-floors can be related to three geomorphic variables: drainage area, A_d; valley gradient, G_v; and valley-floor width, W_v. The area-gradient index, AGI, is the product of A_d and G_v. The relation between W_v and AGI defined the valley-erosion threshold. Most stable reclaimed valley-floor reaches plotted above this threshold, whereas most unstable reclaimed reaches plotted below the threshold. The erosion potential of a reclaimed valley-floor reach can be quantified based on the valley-erosion index, VEI. The valley-erosion threshold and the VEI are empirically derived relations that may be applicable for many reclaimed valley-floors in northwestern Colorado. These geomorphic relations may be useful as planning tools in future reclamation projects.

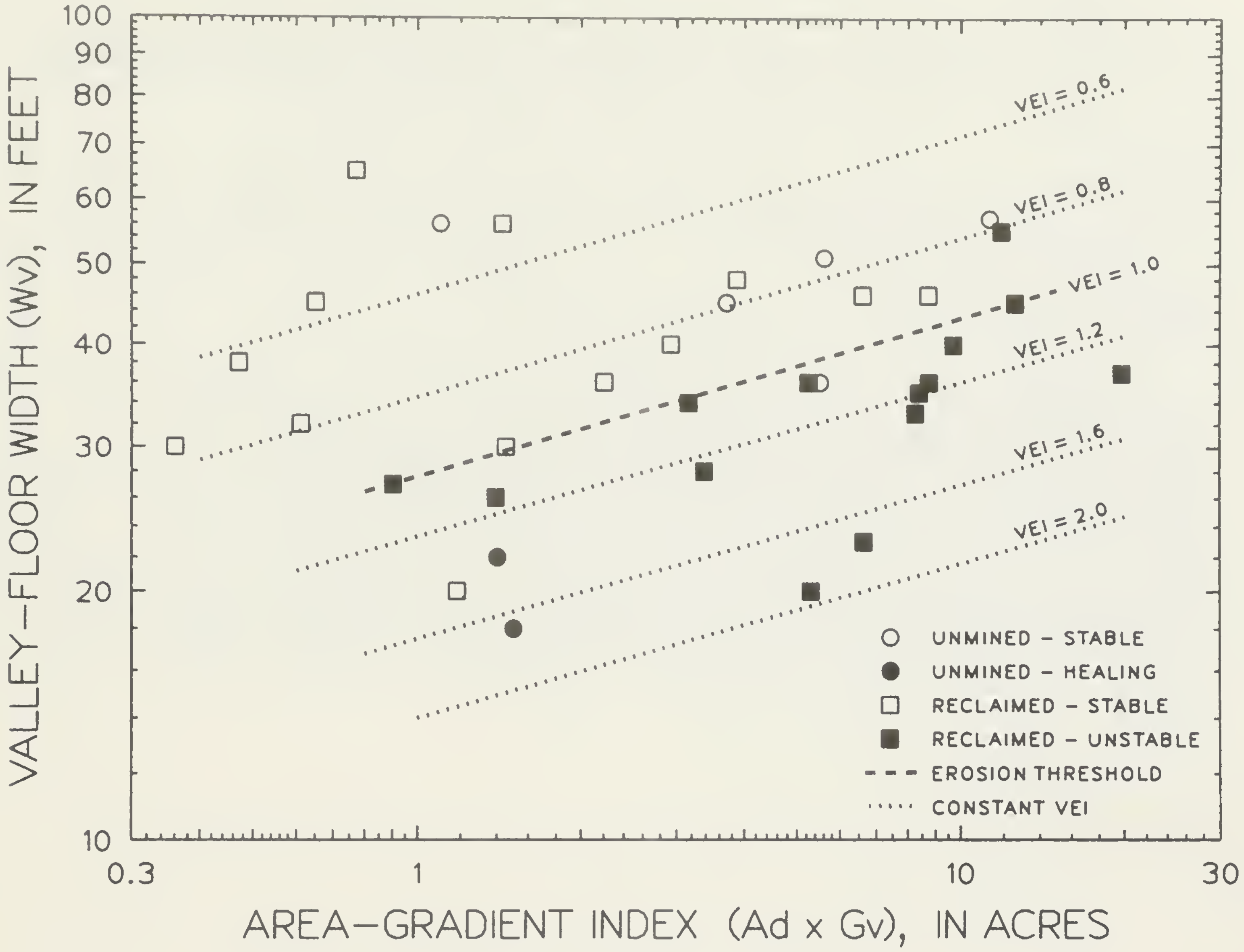

FIGURE 3. Valley-floor width compared to area-gradient index with lines of constant valley-erosion index.

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EVALUATION OF ALTERNATIVE SEDIMENT CONTROL TECHNIQUES AT SURFACE MINES IN THE SEMIARID WEST

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ABSTRACT

This paper describes an investigation conducted to evaluate the potential for alternative sediment control techniques, which encompass standard surface manipulation and reclamation practices, to maintain sediment yields within natural (background) levels at several western coal mines. A combination of field measurements, rainfall simulation testing and mathematical computer modeling was used to evaluate various sediment control techniques. Major objectives were: (1) to determine background levels of sediment yield, (2) to determine if alternative sediment control techniques can meet background levels of sediment yield, and (3) to develop procedures to determine the effectiveness of various combinations of alternative sediment control techniques.

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INTRODUCTION

Federal and state regulations governing coal mine operations mandate the use of the "best technology currently available" (BTCA) for sediment control and prevention of additional contributions of suspended solids to stream flow or runoff outside the mine permit boundaries. Furthermore, until recently, federal regulations specified that all surface runoff from mine operations had to be passed through a sediment pond (30 CFR 816.46(b)(2)). The singular interpretation that sediment ponds represented the BTCA for sediment control was complicated by a U.S. District Court decision (Flannery, 1985). The ruling stated that it cannot conclusively be demonstrated that sedimentation ponds represent BTCA and, hence, alternatives to sedimentation ponds must be given due consideration in permitting and regulation of surface coal mine operations. Water Engineering & Technology, Inc. (1987) documented the adverse impacts that can be caused by sedimentation ponds and the release of clear water into western alluvial stream channels that may naturally have very high sediment loads. Currently, the Office of Surface Mining (OSM) and state regulatory agencies consider the use of alternative sediment control measures on a site-specific basis. Although the focus has shifted from use of sediment ponds to alternative practices, information generally has been lacking to determine if alternative sediment control represents BTCA. Furthermore, procedures and criteria for evaluating the effectiveness of alternative sediment control also are needed.

Bergstrom (1987) describes detailed field data collection and statistical analyses conducted to verify that sediment yield rates from mined land do not exceed natural, or background, rates from comparable undisturbed watersheds. Likewise, Toy (1987) describes a detailed monitoring program to measure and compare sheet erosion rates from both mined and undisturbed hillslope surfaces. The purpose of both of these investigations was to demonstrate that normal mined-land reclamation practices are effective in maintaining sediment yields comparable to background conditions.

This paper describes a comprehensive program conducted by Water Engineering & Technology, Inc. (WET) that was undertaken to: 1) determine if alternative sediment control techniques can maintain sediment yields from disturbed lands at or below background sediment yield rates and 2) develop procedures for evaluating alternative sediment control practices.

The research effort was funded jointly by the Office of Surface Mining (OSM) and three coal mining companies - BHP/Utah International, Inc., Peabody Coal Company, and the Pittsburg & Midway Coal Mining Company. Respective mines where the field data collection efforts were undertaken were the Navajo Mine, located in northwestern New Mexico, the Black Mesa Mine in Arizona, and the McKinley Mine in New Mexico. The National Coal Association administered the contract for the study effort.

Procedures

The rainfall-runoff-erosion process is highly complex. Runoff and erosion in the semiarid western states are generally governed by the occurrence of extreme events exhibiting high temporal and spatial variability (Fogel, 1969; Renard et al., 1974). In the semiarid west, rainfall intensity, has been shown to be a controlling factor in generation of runoff and erosion (Hickok and Osborn, 1969). Screiber and Kincaid (1967) reported that variations in rainfall intensity for periods of less than five minutes accounted for much of the variation in runoff and discharge.

Runoff and erosion response to rainfall also is influenced by physical and environmental factors, ranging from soil properties (antecedent soil moisture conditions, particle size distribution, infiltration rates, etc.) to watershed topography (slope gradient, slope length, drainage density, etc.), vegetation type and density, and surface detention and roughness. Since the runoff-erosion response is governed by interrelated physical processes, it was decided early in the course of this study that alternative sediment control could not be addressed in a purely empirical or statistical fashion. Developing a data set to statistically evaluate alternative sediment control techniques (ASCT) along the lines of development of the Universal Soil Loss Equation (USLE) would potentially require hundreds of tests to develop statistical confidence in the derived relationships. To avoid this problem, it was decided to conduct field data collection to develop a database sufficient for calibration and validation of an existing watershed computer model. If the model were successfully calibrated and validated, it could be applied to evaluate conditions not specifically tested in the field. Use of an existing model was a requirement because it was desired to use a model incorporating applied and tested methodologies for computation of rainfall induced runoff and soil loss.

MODEL EVALUATION

Computer modeling of hydrologic processes is a commonly used method of evaluating watershed response and assessing impacts of land use change or development. Modeling techniques are particularly valuable in semiarid western states because the infrequency of natural rainfall and runoff discourages compilation and analysis of data from instrumented watersheds. The initial focus of the study was to evaluate and select the best available mathematical model for predicting runoff and sediment yield rates from surface mined lands in semiarid climates. The selected model subsequently was calibrated using the field data and applied to evaluate combinations of conditions that could not be tested in the field.

Table 1 shows the models considered in this evaluation. These models were selected for consideration based on the investigators' personal knowledge, through a literature survey and through contacting scientists and engineers active in watershed modeling research. It was beyond the scope of the project to evaluate every available watershed computer model, although it is believed that the models indicated in Table 1 are a representative cross section of those available at the time of the evaluation. Detailed evaluations and comparisons were made of five of the models (denoted with an * to the left of the model acronym in Table 1) with respect to: 1) watershed representation, 2) rainfall components, 3) infiltration, interception and surface detention components, 4) runoff component, 5) sedimentation components, 6) ease of data file generation, 7) performance with a test data set from a heavily instrumented watershed, and 8) sensitivity analyses of the various input variables and parameters.

Table 1 Hydrologic models considered during model evaluation portion of study effort.

*	**ANSWERS**	Areal Nonpoint Source Watershed Environmental Response Simulation - Purdue University
	ARDBSN	Arid Basin Model
	CREAMS2	Chemicals, Runoff and Erosion of Agricultural Managements Systems II
*	**KINEROS**	A Kinematic Erosion Model
*	**MULTSED**	Watershed and Sediment Runoff Simulation Model for Multiple Watersheds
*	**PRMS**	Precipitation - Runoff Modeling System
*	**SEDIMOT II**	Hydrology and Sedimentology Watershed Model II (SEDCAD+ Version)
	SP	Simplified Process Model
	SWRRB	Simulation for Watershed Resources in Rural Basins
	WEPP	Watershed Erosion Prediction Project

As a result of these analyses, the MULTSED model, developed at Colorado State University with support from the Environmental Protection Agency (EPA) and USDA-Forest Service (Simons et al., 1980, 1981; Fullerton, 1983) was recommended and adopted for use in subsequent phases of the project. Zevenbergen and Peterson (1988) describe the model evaluation procedures in more detail.

DATA COLLECTION

On-site rainfall simulation testing was conducted at the Navajo and McKinley mines to develop a database for evaluation of alternative sediment control techniques commonly used at surface coal mines. Because testing included sites affected by mining operations (disturbed and reclaimed) as well as unmined sites within the mine leasehold, the data were used to compare the sediment yield from lands treated using alternative sediment control techniques with background sediment yield. Field data collection efforts were undertaken at the Navajo and McKinley mines using portable rainfall simulators patterned after a system developed at Colorado State University (Holland, 1979). This system has been widely used to evaluate the rainfall-runoff-erosion process at surface mines and other disturbed sites (Lusby and Toy, 1976; Neff, 1979; Simons et al, 1980; Peterson, 1984). The advantages of this system include ease of assembly, ability to adapt to various surface conditions, uniformity of rainfall coverage, and a drop size distribution approaching that of comparable natural rainfall. The simulation system is not able to fully reproduce the kinetic energy of natural rainfall, however.

At each mine, test sites encompassing a range of slopes, ages of reclamation, soil types, vegetative cover densities and other surface conditions were identified. Test sites were located on undisturbed, reclaimed and disturbed sites throughout each mine. Rainfall simulation testing was conducted using paired test plots at 19 locations on the Navajo Mine and 20 locations on the McKinley Mine. Test plots 12 feet wide and 35 feet long were defined using sheet steel borders. Collector troughs, rain gages and other components of the data collection system were fabricated and installed using criteria for such systems outlined by Meyer (1988) and the Agricultural Research Service (1979).

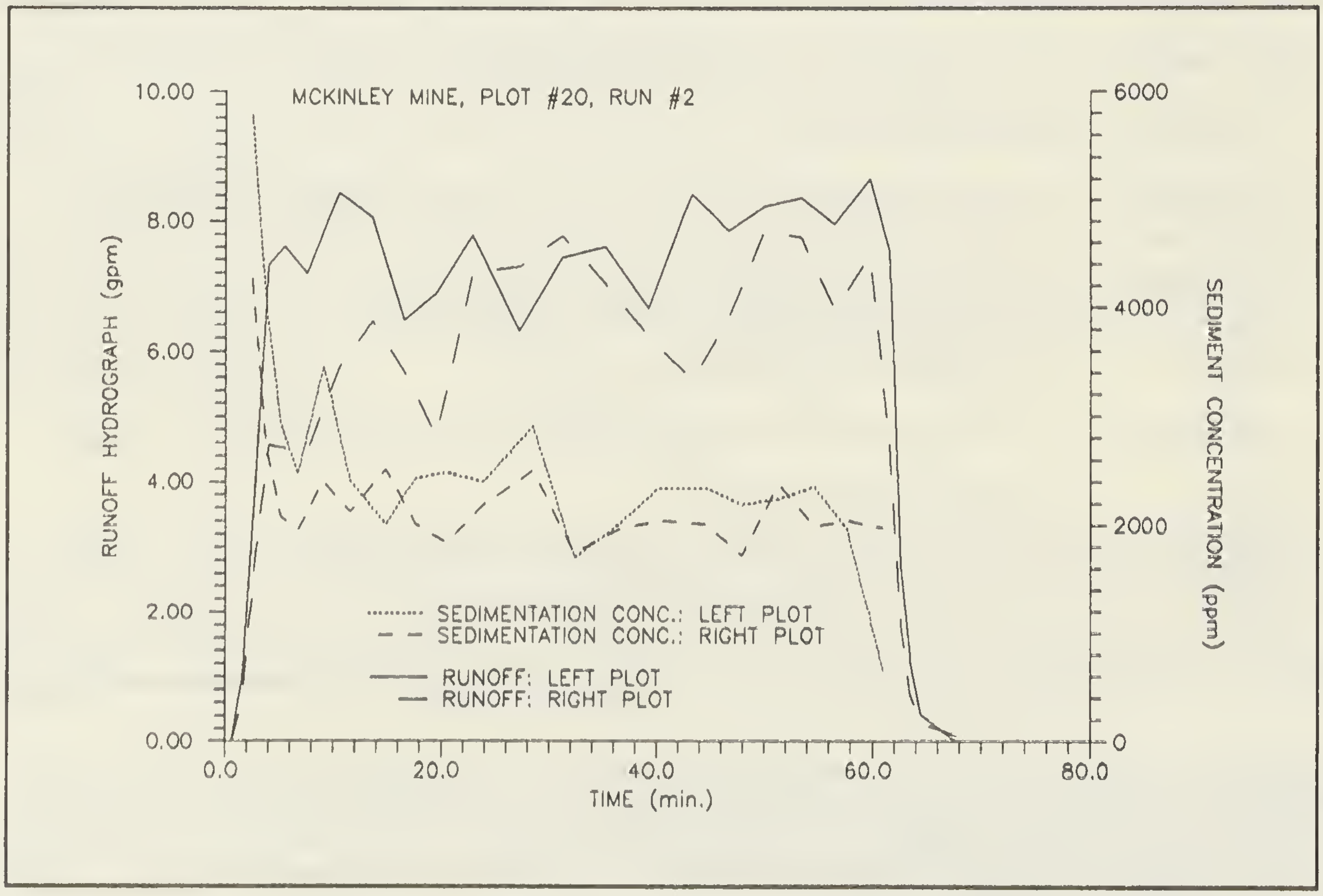

Figure 1 Runoff and sediment concentration for a rainfall simulation test at the McKinley Mine.

The test program involved application of simulated rainfall at an intensity of 3 inches per hour for a period of approximately one hour. The test sequence involved an initial run under antecedent soil moisture conditions that are generally relatively dry in the semiarid west, followed approximately 24 hours later by a second test run to obtain data for wet soil conditions. Data were collected prior to, during and/or after each test run to compute antecedent soil moisture conditions, bulk densities, soil particle size distributions, rainfall amounts, runoff rates and amounts, and sediment concentrations and total sediment yield. To accurately define runoff and soil loss response to rainfall, runoff rates and sediment concentrations were measured at three to five minute intervals throughout the duration of each test run. As a result of the rainfall simulation testing, 76 measures (19 test sites x 2 plots/site x 2 runs) of rainfall-runoff-soil loss response were available for the Navajo Mine and 80 for the McKinley Mine. Figure 1 is an example of the detailed runoff and sediment concentration measurements collected from paired test plots at each mine.

At the Black Mesa Mine, data have been collected from 24 test plots (10 ft. wide by 35 ft. long) under natural rainfall conditions during the last several years. In addition, data have been collected from five small, undisturbed and reclaimed watersheds on the mine using monitoring systems consisting of recording rain gages and supercritical flumes with pumped sediment samplers and automatic stage recorders. These represent some of the most complete and comprehensive data that have been collected on a western surface coal mine under natural rainfall conditions. This information, along with detailed analyses of soils and cover characteristics, were used to calibrate and validate the MULTSED physical process computer model.

MODELING RUNOFF AND SOIL LOSS

One-half of the available field data were used to calibrate the MULTSED model to represent plot conditions, with the remaining portion of the data set retained for subsequent validation. Pertinent physical conditions at each test site were represented. Calibration first was conducted for runoff and then for soil loss. Figure 2 shows the comparison between measured and predicted

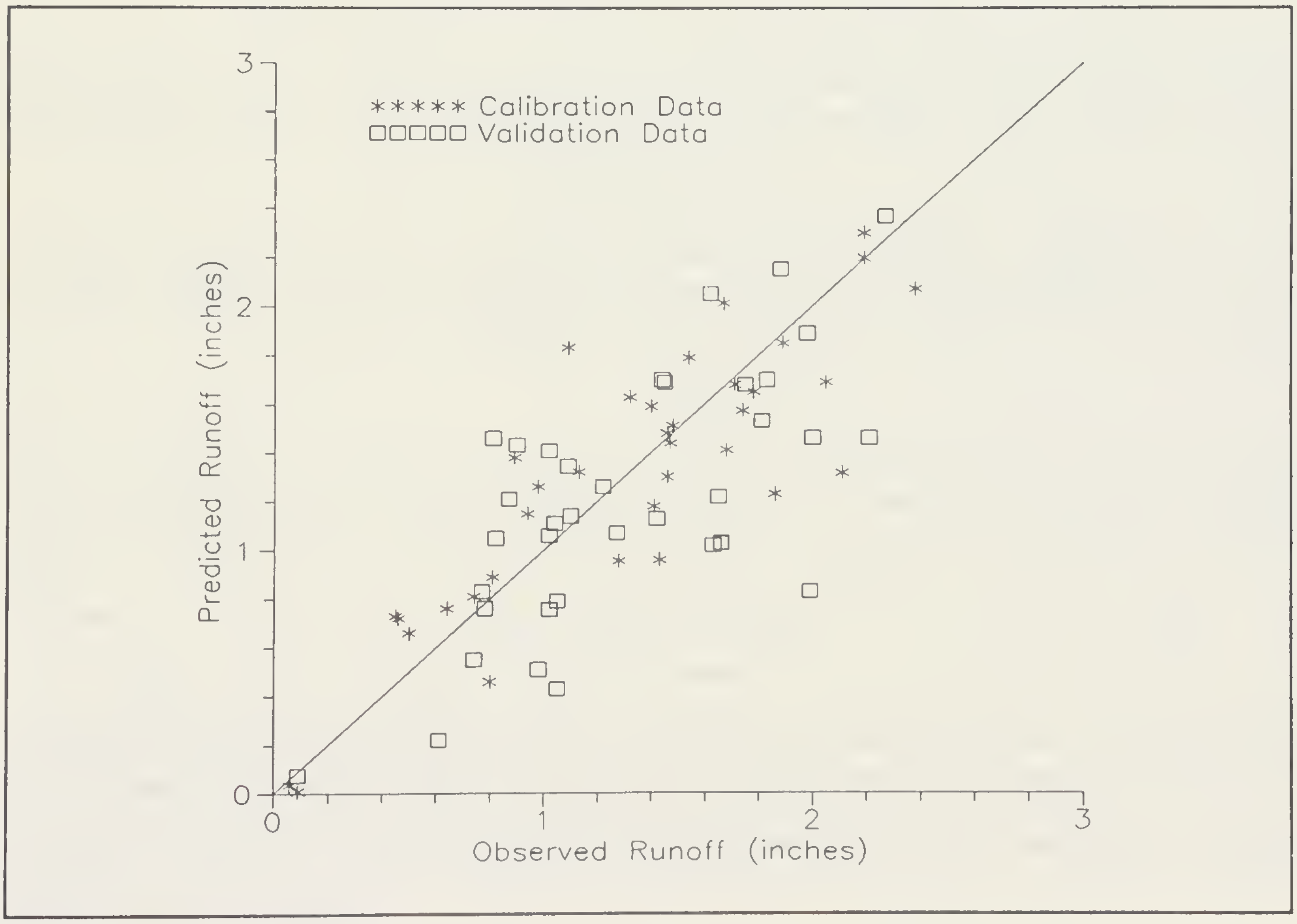

Figure 2 Observed versus predicted runoff - McKinley Mine

values for runoff for both the calibration and validation data. It should be emphasized that only average values of soil properties for each soil type, such as hydraulic conductivity, were used in the calibration. The emphasis was on description of average soil properties rather than micro-scale differences in soil response.

In general, model calibration indicated a slight reduction in hydraulic conductivity of post-mine soils, as compared to undisturbed soils having generally similar characteristics (particle size distribution, textural composition, antecedent soil moisture, etc.). Schroeder (1987) noted similar tendencies in a study of runoff-erosion response from grasslands sites at mines in South Dakota.

EVALUATION OF ALTERNATIVE SEDIMENT CONTROL

Procedures

The major variables controlling average sediment yield from a hillslope surface, assuming average rainfall input and soil characteristics such as infiltration capacity remain unchanged, are: 1) slope length, 2) slope gradient, 3) ground and/or canopy cover densities and 4) surface depression storage, represented by features such as contour furrows that serve as catchments for storage of rainfall and runoff at the surface mine. Alternative sediment control techniques basically involve modification of one or more of these characteristics to maintain sediment yield at or below an allowable erosion rate. For purposes of the investigation described in this paper, the allowable erosion rate was defined relative to erosion rates from undisturbed lands (background sediment yield) as predicted using the calibrated MULTSED watershed model.

The calibrated watershed model for each mine was applied to evaluate various combinations of plot slope, slope length, rainfall input, percentages of canopy and ground cover, and amounts of depression storage to evaluate the effectiveness of postmining reclamation procedures relative to background conditions. The model was used to extend the results derived from the test plot data since all possible combinations of conditions could not be tested in the field.

The constant-intensity simulated rainfall used for data collection is unrealistic when compared to the highly variable rainfall rates of a typical thunderstorm. To compare the undisturbed and reclaimed plots, an analysis using a range of realistic rainfall hyetographs is most appropriate. Hypothetical storm distributions for storm events having recurrence intervals of 2, 5, 10, 25, 50 and 100 years were developed using data from the NOAA atlases (Miller et al., 1973). Runoff and soil loss response to these storm events were modeled using MULTSED. An average weighted soil loss was computed by weighting the various storm event sediment yields according to the incremental probability of occurrence using a relationship described by Lagasse et al. (1983).

Results

Figure 3 is a simple example of the results obtained from evaluation of slope length effects on soil loss from a loam soil located on a small hillslope plot having a 15 percent slope at the McKinley Mine. Actual particle size distributions and calibrated model parameters (hydraulic conductivity, etc.) were used to describe the undisturbed and reclaimed soils. Figure 3 shows the difference between reclaimed and background soil response and the effects that slope length changes or addition of furrows have on erosion response. Figure 3 shows that for comparable conditions, potential erosion rates from reclaimed soils are roughly two times greater than background erosion rates. This increase is in large part due to a lower hydraulic conductivity for the reclaimed soils in comparison to undisturbed soils. From Figure 3, the change in slope length required to maintain erosion rates from a hillslope surface at or below background erosions can be evaluated. For example, if unmined hillslope lengths averaged 200 feet, reclaimed slope length would have to be reduced to about 100 feet to develop comparable erosion response, holding all other conditions constant.

Figure 3 also shows that addition of furrows that provide depression storage of either 0.1 inch (small furrows) or 0.3 inch (larger furrows) significantly reduces erosion potential of the

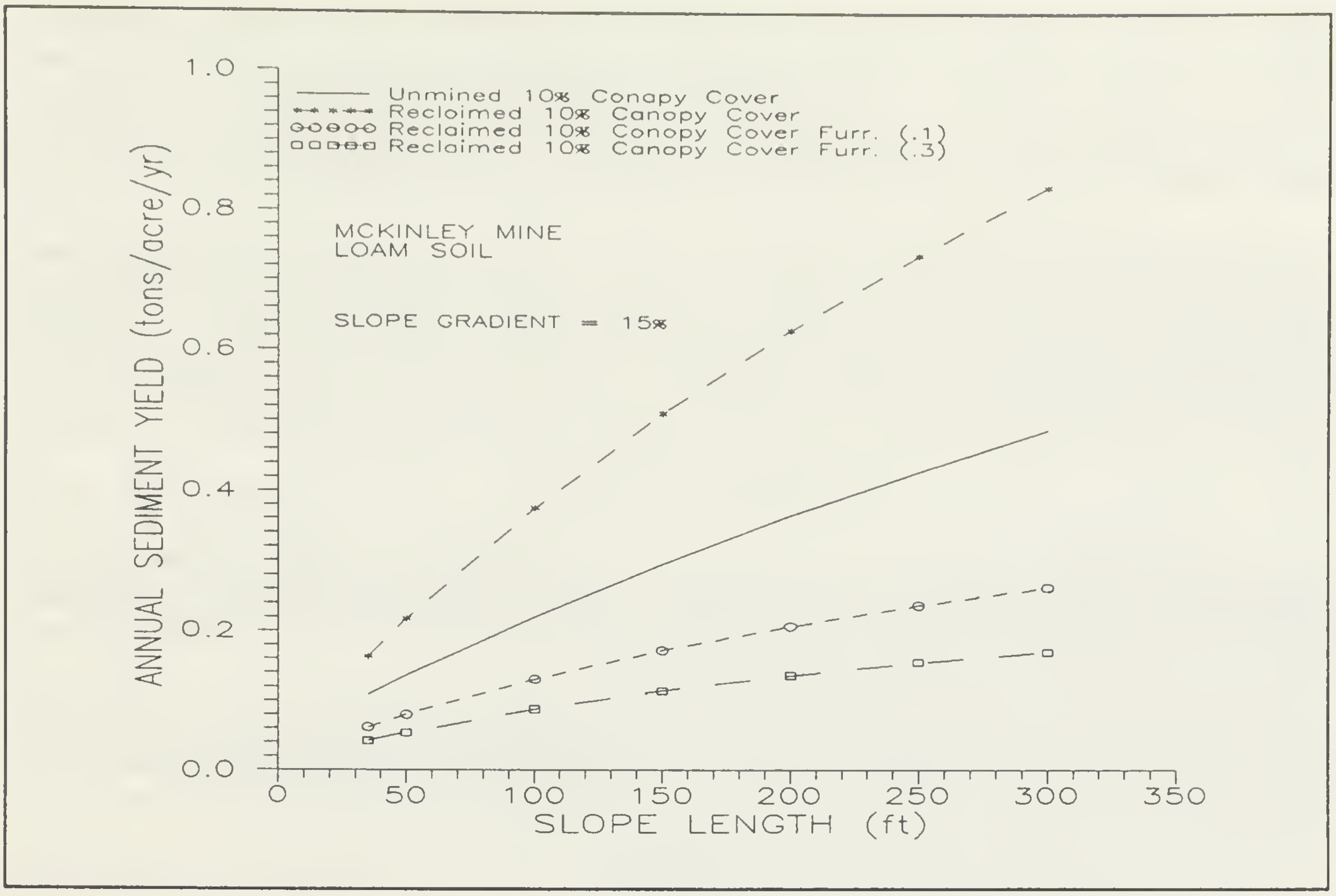

Figure 3 Average sediment yield versus slope length for a loam soil at McKinley Mine.

reclaimed surface. The effectiveness of contour furrows, however, decreases with time (Branson et al. 1966). Thus, although contour furrows are a form of alternative sediment control, they should generally be considered to be a temporary or supplemental measure.

CONCLUSIONS

This investigation determined that alternative sediment control techniques involving: 1) manipulation of slope length, 2) manipulation of slope gradient, and 3) increasing the amount of permanent surface cover such as vegetation or rock mulch can potentially be used either alone or in combination to augment normal reclamation practices consisting of topsoiling and revegetation. These techniques promote reclaimed conditions that support the approved postmine land use while maintaining the prevailing hydrologic balance and preventing any additional contributions to sediment yield beyond the mine permit boundary. A fourth form of alternative sediment control would include measures to increase the infiltrative capacity of the postmine soils. Such measures were not specifically examined in this investigation and are an area where further information is needed.

RECOMMENDATIONS

To determine whether a specific combination of alternative sediment controls meets background conditions, use of the MULTSED model is required. Application of MULTSED requires use of site-specific data describing: 1) vegetative cover densities, 2) slopes of hillslopes and channels, 3) lengths and general dimensions of channels, 4) lengths of hillslopes, 5) soil particle size information for channels and hillslopes and 6) soil infiltration capacity data. Information describing soil infiltration characteristics is the major factor for calibration and could best be obtained using rainfall simulation techniques.

When properly calibrated, the MULTSED model is capable of simulating erosion and sediment yield resulting from the complex interaction of varying slope length, gradient, cover and depression storage. Furthermore, the MULTSED model allows for evaluation of both channel and hillslope processes, providing a means to investigate total watershed response. The strength of MULTSED in evaluating and quantifying the effectiveness of alternative sediment control techniques is the fact that MULTSED breaks the system down into the governing component processes (i.e. infiltration, rainfall splash detachment, routing of sediment by particle size fraction).

Purely empirical techniques such as the Universal Soil Loss Equation (USLE) require extensive field testing to adequately model a reclamation method. Physically based models such as MULTSED require only data necessary to describe the governing physical process. No model is perfect; however, the developments in understanding of the theory and in computational methods for assessment of watershed processes that have occurred during the intervening time since development of the USLE, modified USLE, etc. should be recognized and applied.

ACKNOWLEDGEMENTS

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The views and opinions expressed in this paper are those of the authors and do not necessarily represent those of the Office of Surface Mining, National Coal Association, BHP/Utah International, Inc., Peabody Coal Company, or the Pittsburg & Midway Coal Mining Company.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

RUNOFF AND EROSION FROM NATIVE AND RECLAIMED SITES: LARGE VERSUS SMALL PLOTS

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ABSTRACT

Runoff and erosion were compared using rainfall simulators on small (1 m^2) and large (3 x 10.67 m) runoff plots. Four small and two large plots were located on each of eight sites. These included two native sites dominated by bunchgrasses and shrubs on sandy dunes, two nearly barren badlands, two 10 year-old reclaimed sites treated with topdressing and dominated by bunchgrasses and shrubs, and two first year reclaimed sites treated with topdressing and dominated by annual forbs and wheat.

Rainfall was more uniform and more easily controlled on small plots than large plots. Many small plots (at least eight) could be rained on each day by using wind screens while large plots required calm winds during simulated rainfall which was delayed for many days on numerous occasions. Results from small plots were as accurate and more precise than from large plots on native and reclaimed sites where slope lengths were truncated by shrubs and bunchgrasses. Runoff and erosion from small plots could be measured quickly and cheaply for evaluating reclamation success.

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INTRODUCTION

Runoff and erosion can be used as part of an evaluation of reclamation success. Amounts and rates of runoff and erosion can be determined by two general methods: (1) Plot studies of natural rainfall or artificial applications of water, and associated runoff and erosion and (2) analysis of rainfall, basin characteristics, and runoff data from natural watersheds. A combination of the two methods may also be used. Because of the time (many years), high costs, and variability associated with analysis from natural watersheds, plot studies with rainfall simulators have been widely used in the western U.S. since the early 1930's. They are considered to be important devices for gathering data that can be analyzed to define the hydrologic and hydraulic characteristics of natural and disturbed lands. Several bibliographies provide information on plot sizes, portability, and simulated rainfall characteristics (Birk et al. 1979, USDA 1979, and Cook and Stubbendieck 1986). Advantages and limitations of rainfall simulators have been discussed by Mech (1965).

Large plots (3.0 x 10.7 m) require at least a day of set-up time and another day to apply rainfall and dismantle for each plot. They can be greatly influenced by wind with delays being common. The initial part of the runoff curve is of primary importance to soil water storage and infiltration on rangelands. In much of the rangeland, most rains fall on dry soil and are frequently of high intensity. Application of water on dry plots gives information on the infiltration and runoff characteristics to be most often expected under most conditions. For long duration storms, the minimum infiltration rate that prevails after the soil is thoroughly wet is the critical value for initiating runoff and erosion. This critical value is obtained in plot studies by means of a second application of water to the same plot, usually 24 hours after the first rainfall application (Rauzi and Smith 1973). Therefore, the entire cycle may be easily disrupted using large plots if applications do not coincide with two subsequent calm days. As a result, cost per large plot is high and sample sizes usually are low. However, large plots may be used to more easily characterize mean conditions with large spatial variations and to measure erosive response due to long slope lengths on bare soils. Commonly 10 small plots (1 m^2) may be installed and rained on each day with the same number of workers required for large plots. Wood and Blackburn (1981) reported 20 plots installed and rained on for one ambitious day. Hence, costs per plot can be low and sample sizes and the number of treatments evaluated can be high.

The objective of this study was to compare runoff and erosion from small plots (1 x 1 m) to large plots (3.0 x 10.7 m) located on a variety of native and reclaimed areas on the Navajo Mine located in northwestern New Mexico.

METHODS

Simulated Rainfall

Eight different sites were located: four on native and four on reclaimed areas. Each of the sites had two large plots (3.0 x 10.7 m) and four adjacent small plots (1 x 1 m) on the same soil, vegetation, slope, and exposure. Specific locations of the large and small plots were chosen randomly from a large pool of locations that resembled the conditions associated with each site. These included two native sites dominated by bunchgrasses and shrubs on sandy dunes, two nearly barren badlands, two 10 year old reclaimed sites treated with topdressing and dominated by bunchgrasses and shrubs, and two first year reclaimed site that were treated with topdressing and dominated by annual forbs and wheat. The small and large plots were installed with a metal border and a catchment tray on the downhill side.

Simulated rainfall was applied to the small plots at a rate of 14.35 cm hr^{-1} for 30 minutes or 7.18 cm total. This rate assured runoff from all areas so that plot differences could be determined. An attempt was made to apply rainfall to the small plots at the same rate and duration as that applied to the large plots. But the application rates and durations differed from large plot to large plot. Application rates varied from 4.88 to 7.37 cm. Comparisons were then made by calculating the regression equation for each plot which expressed cumulative runoff as a function of cumulative rainfall on the small plots. These equations represented correlations close to R^2=0.98. Mean total rainfall from the large plots for each site was put into the equation to obtain a mean runoff value for the small plots that represented the rainfall amounts applied to the large plots. Comparisons could then be made for depth of runoff between large plots and small plots for a given rainfall depth.

The rainfall simulator used for the small plots was described by Wilcox et al. (1986). The rainfall simulator used for the large plots was described by Holland (1969). Simulated rainfall was applied at antecedent (dry) soil conditions and 24 hours later when soil moisture conditions were near field capacity (wet). After the first rainfall application, the small plots were covered with sheets of clear plastic to prevent evaporation and assure homogeneous soil moisture conditions. The large plots were not covered because of inconvenience and arrangement of equipment.

Runoff

Runoff from the plots was drained into a collection tank and measured by volume for each 5-minute interval for 30 minutes. Time (minutes) until ponding occurred was also recorded.

Sediment Concentration and Production

A 1-liter sample of the mixed runoff was used to determine the amount of suspended sediment in the runoff. Sediment was separated from fluid by decantation of the clear aqueous portion after settling. The remaining sediment and water was transferred to a preweighed petridish and oven-dried at 60° C. The sediment was then weighed. The data were converted to concentration (kg m^{-3}) and also to weight per unit area. (t ha^{-1}).

RESULTS

Runoff

It has long been thought that large plots have an advantage over small plots because they include the influences of slope length. On bare croplands with long, homogeneous fields, this is probably true. It has also been suspected that slope lengths are very short on rangelands vegetated with shrubs, grasses and forbs and differences between long and short plots would be much less than the differences on croplands.

Comparisons of runoff depths from large and small plots for various treatments and rainfall depths are shown in table 1 and graphically in figure 1. Coefficient of determination (R^2) was 0.36. The F-ratio was 8.35 which was highly significant. Figure 1 shows four large plot values that are very high compared to small plot values. These came from the newly reclaimed plots that were dominated by forbs and wheat. Table 1 shows 87% of the precipitation resulting in runoff for reclaimed plot #3. This is attributed to experimental error which is often greatly associated with large plots. Without the four suspect plots being included, the correlation of determination (R^2) was 0.80 and the F-ratio was 40.08 which was highly significant.

Mean runoff from large plots was 2.939 cm and from small plots 2.591 which is 88.2% of 2.939. Considering variation of hydrologic data from other studies, these runoff values are considered to be very close. This was verified with covariance analysis which showed mean runoff from large plots was significantly greater than runoff from small plots at $P = 0.05$ but not at $p = 0.10$. Ponding times were not significantly different.

Sediment Concentration and Production

Comparisons of sediment concentration from large and small plots for various treatments are shown in table 2 and graphically in figure 2. The values for badlands are all extremely high expressing their highly erosive nature. Results from both reclaimed sites showed a significant improvement over the widely distributed badlands on the mining lease. The R^2 for sediment concentration between large and small plots was 0.87 with an x-coefficient of 0.7113 meaning the correlation is considered very high for hydrologic data and small plot data can be transformed to comparable large plot data by dividing the small plot value by 0.7113. The F-ratio was 110.01 which is highly significant ($p < 0.001$).

Some of the values for large plots seem to be highly variable and inconsistent which is believed to be an inherent problem with trying to apply simulated rainfall over such a large area. An example is native plot #1 where sediment concentration tripled from the dry to wet run, but for native plot #2 the wet run only had half as much sediment (table 2). The situation in plot #1 is consistent with data collected under natural conditions.

Comparisons of total sediment yield or loss from large and small plots for various treatments are shown in table 3 and graphically presented in figure 3. Like sediment concentration, the values for badlands are extremely high while the other values are quite low and within the ranges usually considered to be acceptable tolerance levels. The R^2 value between large and small plots was 0.921 which is very high for hydrologic data. The F-ratio was 171.26 which is very significant ($p < 0.001$). The x-coefficient was 1.478 meaning small plot data can be transformed to comparable large plot data by dividing by 1.478.

SUMMARY

In summary, the results show a high correlation (R^2) between runoff, sediment concentration, and total sediment yield or loss between large and small plots. The F-ratios were all significant which means the slope of the lines expressing the relationships (figures 1-3) are real. After considering the characteristics of both plot sizes (time, costs, precision, and accuracy), small plots can be used in shorter periods of set-up and take-down time with less workers. This results in more plots (replications) which allows for more precise evaluations of many more conditions. Small plots were determined to be as accurate and have much greater precision.

Table 1. Total rainfall and runoff depths (cm) from large and small plots.

Sites	Soil Condition	Rainfall	Runoff Large Plots	Runoff Small Plots
Native #1	dry	7.04	0.91	1.47
	wet	4.88	3.00	1.70
#2	dry	6.48	0.76	1.35
	wet	5.08	1.07	1.78
Badlands #1	dry	6.25	2.34	2.56
	wet	5.87	5.28	4.60
#2	dry	5.54	3.28	2.08
	wet	6.07	5.08	4.78
Reclaimed #1	dry	6.68	3.10	2.54
	wet	5.51	3.96	3.02
#2	dry	5.74	2.72	2.13
	wet	5.59	3.76	3.07
#3	dry	6.50	1.30	0.10
	wet	7.37	6.45	1.30
#4	dry	5.46	1.14	0.05
	wet	6.35	3.23	0.96

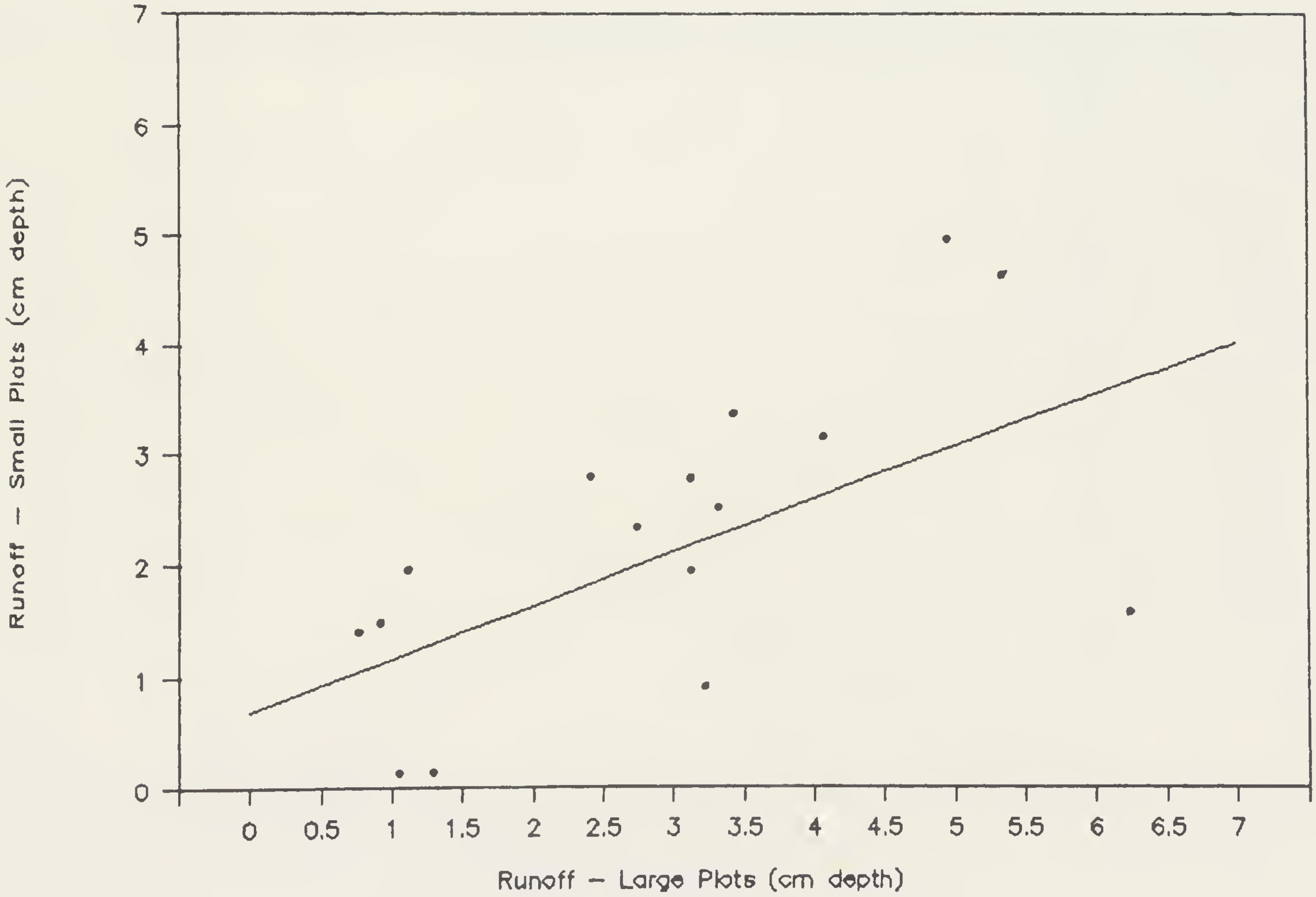

Figure 1. Runoff from large plots versus runoff from small plots for all sites.

Table 2. Sediment concentration (kg m^{-3}) from large and small plots.

Sites		Soil Condition	Sediment Concentration Large Plots	Sediment Concentration Small Plots
Native	#1	dry	442	4,012
		wet	1,323	4,540
	#2	dry	860	4,142
		wet	425	3,080
Badlands	#1	dry	72,850	53,232
		wet	63,600	61,278
	#2	dry	68,150	29,120
		wet	70,900	51,790
Reclaimed	#1	dry	1,660	4,058
		wet	2,225	12,585
	#2	dry	3,980	8,285
		wet	6,475	10,600
	#3	dry	1,740	348
		wet	1,045	1,050
	#4	dry	482	380
		wet	672	518

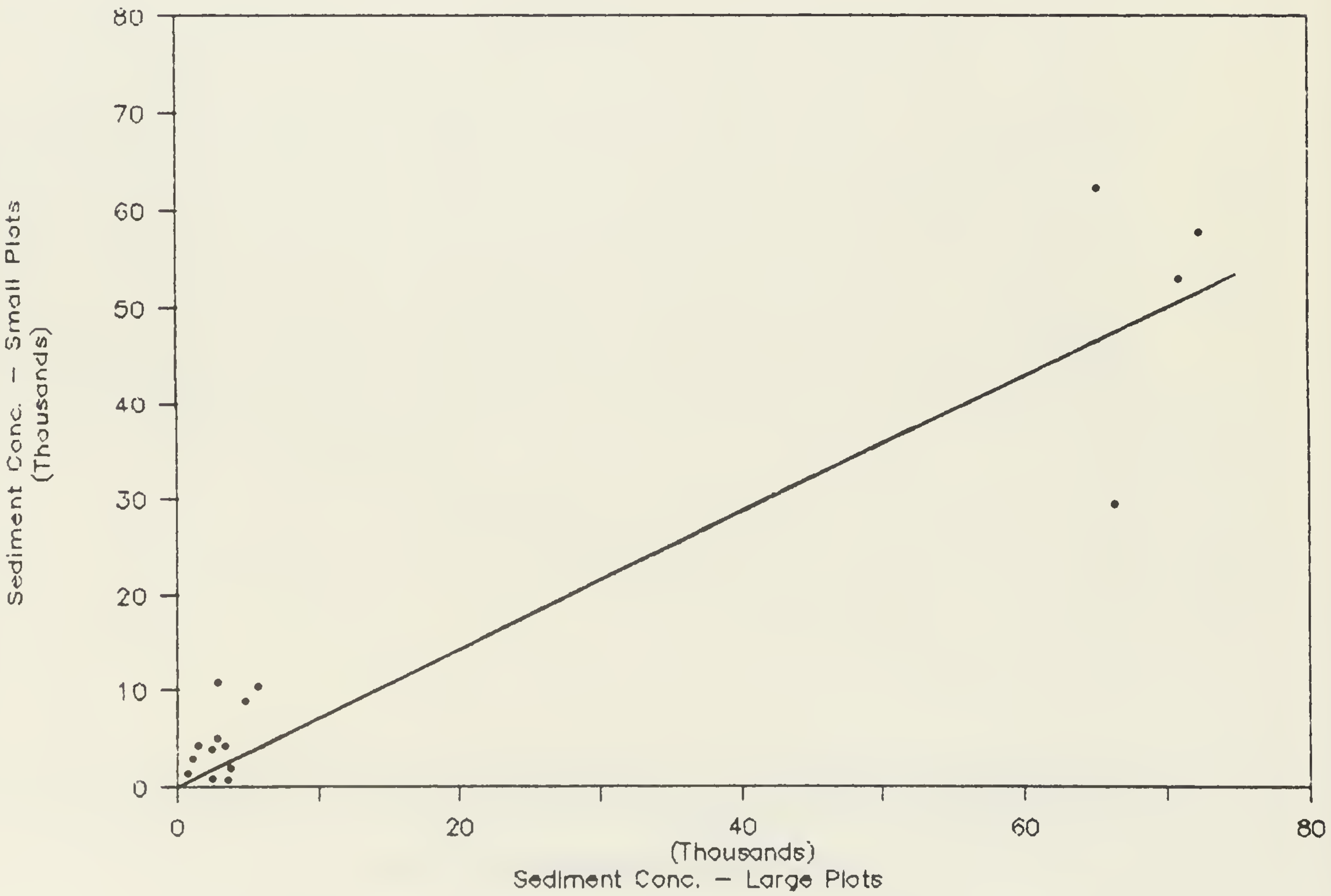

Figure 2. Sediment concentration from large plots versus runoff from small plots for all sites.

Table 3. Total sediment yield (t ha^{-1}) from large and small plots.

Sites	Soil Condition	Total Sediment Yield Large Plots	 Small Plots
Native #1	dry	0.035	1.188
	wet	0.395	2.601
#2	dry	0.029	1.214
	wet	0.047	1.444
Badlands #1	dry	26.285	37.933
	wet	33.833	63.223
#2	dry	22.408	19.869
	wet	36.095	49.242
Reclaimed #1	dry	0.512	1.877
	wet	0.878	8.539
#2	dry	1.070	5.243
	wet	2.425	8.614
#3	dry	0.221	0.005
	wet	0.674	0.324
#4	dry	0.058	0.062
	wet	0.215	0.165

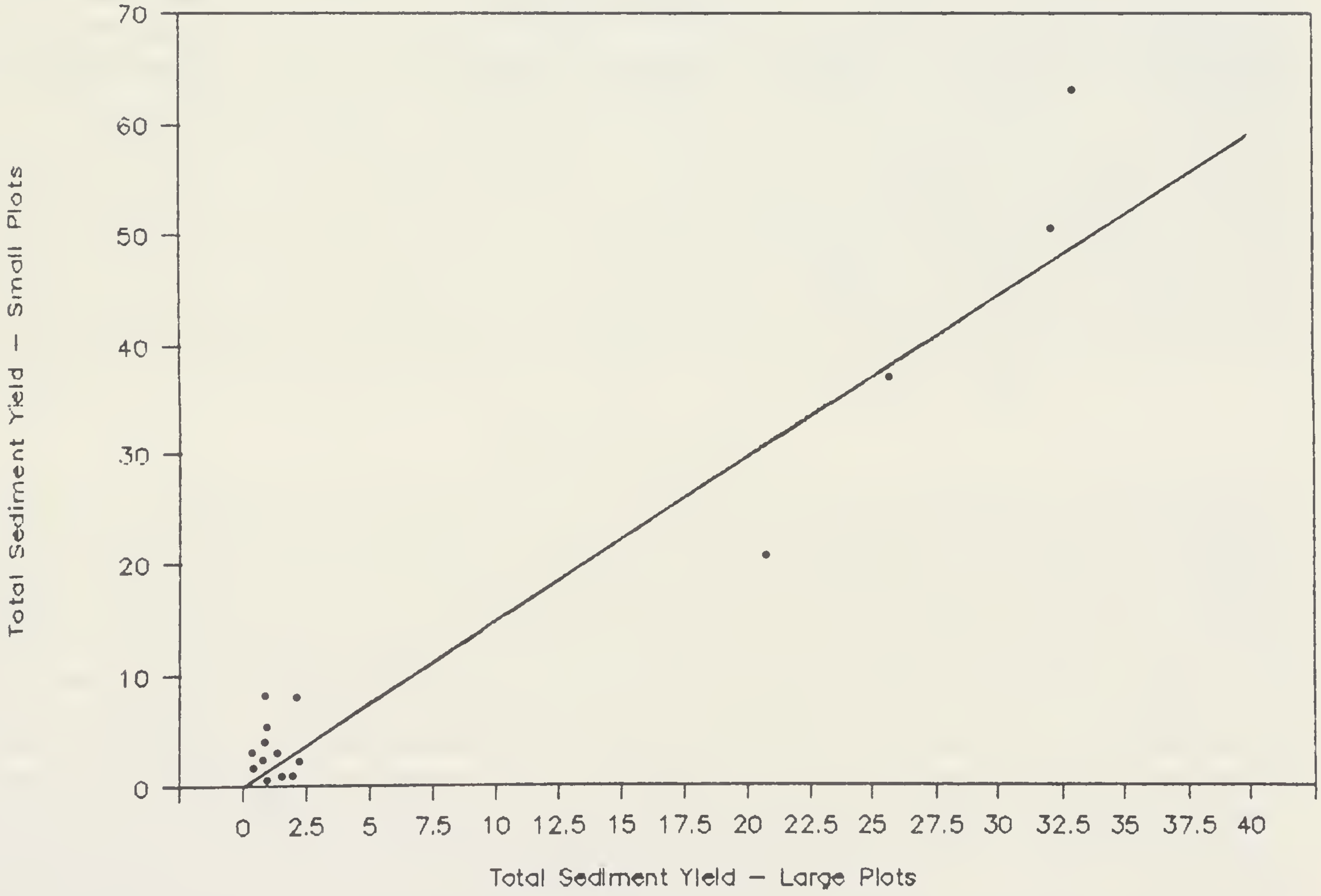

Figure 3. Total sediment yield from large plots versus runoff from small plots for all sites.

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

COMPUTER SIMULATION OF WATERSHED RUNOFF AND SEDIMENTATION PROCESSES

Lyle W. Zevenbergen,[1] Mark R. Peterson[2] and Chester C. Watson[3]

ABSTRACT

Mathematical modeling of watershed sediment production and determination of downstream impact can often be complex and tedious. A watershed runoff and sedimentation modeling program, Erosion And Sedimentation Impacts (EASI) has been developed to aid in the analysis and development of various erosion and sedimentation control practices. It combines a sophisticated watershed modeling program with a user-friendly interface.

EASI can be used to represent and analyze a complex watershed as a network of hillslopes, subwatersheds, channels and ponds, each with uniquely identified soil, rainfall, management and topography or geometry. EASI calculates the runoff and sediment yield for each hillslope or non-point source area, determines the sediment transport capacity for the channels and trap efficiency for ponds, and deposits excess sediment or scours channels when a sediment deficit exists. By analyzing erosion and sediment transport processes throughout the catchment, the model addresses non-point source areas and potential impacts throughout the channel network.

EASI has been used in surface mine reclamation activities and in the analysis of non-point source pollution from agricultural land. It provides regulatory personnel and reclamation managers with a tool to predict and assess the impacts of various land treatments and agricultural practices. The model has been calibrated with data collected from rainfall simulation plots and has been tested with data from agricultural, undisturbed and reclaimed instrumented watersheds. Results of these analyses are presented.

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INTRODUCTION

Computer modeling of hydrologic processes is a commonly used technique to evaluate watershed response and to assess impacts of land use change and development. Modeling techniques are of particular value in semiarid climates because the infrequency of natural rainfall and runoff discourages compilation and analysis of data from instrumented watersheds. This paper describes a project in which various computer watershed models were evaluated in order to select the model which best simulates watershed runoff, erosion and sediment transport processes. The selected computer model (MULTSED) was then developed to assist mine reclamation managers and regulatory personnel in their use of this sophisticated model by providing an efficient environment for watershed model generation. This environment (EASI) combines the MULTSED watershed analysis program with a user interface which includes databases for rainfall events, soil properties and watershed management activities, a digitizer interface for determination of watershed topographic properties, and both graphic and textual presentation of model results. The software is designed to run on IBM AT and compatible computers.

BACKGROUND

Physical Processes

The amounts of runoff and sediment produced by a watershed are controlled by a variety of physical processes which occur within the watershed. During a storm event, rainfall which is not intercepted by vegetative cover, does not infiltrate the soil, or is not retained in surface depressions becomes surface runoff on hillslopes and channels. The presence of vegetative and rock cover helps to limit erosion, as do other factors including soil characteristics and watershed topography. Not all eroded sediment necessarily reaches the channel or watershed outlet because deposition can occur naturally on hillslopes and in channels and can be induced with ponds and other sediment control structures. Therefore, the ideal computer model should accurately represent hillslope topography, channel geometry and the complex channel network in addition to accurately simulating the processes of infiltration, interception, depression storage, soil erosion, sediment transport and sediment deposition on hillslopes, channels and ponds.

Model Selection

A number of numerical models were evaluated as part of this project. Models were excluded from the evaluation if significant aspects of watershed hydrology or sediment transport were not simulated. Five models (SEDCAD, ANSWERS, KINEROS, MULTSED, PRMS) were selected for detailed evaluation (a thorough description of the model evaluation is presented in Zevenbergen and Peterson, 1988). Each model was evaluated by three criteria: 1) degree of physical process simulation, 2) how well the model results compared with observations at an instrumented watershed and 3) the sensitivity of model results to variations in input parameters. The models were most similar with regard to infiltration and runoff response, only somewhat similar in the methods used to predict erosion rates, and dissimilar in the prediction of sediment yield response. The model which performed the best with regard to each of the evaluation criteria was MULTSED (Simons et al., 1978,1981; Fullerton, 1983).

Model Calibration

Data were collected at 24 natural-rainfall plots at Black Mesa Mine near Kayenta, Arizona (Peabody Coal Co.), 38 simulated-rainfall plots at Navajo Mine near Farmington, New Mexico (BHP-Utah International, Inc.) and 40 simulated-rainfall plots at the McKinley Mine near Gallup, New Mexico (Pittsburg & Midway Coal Co.). The data varied significantly in terms of geology, climate, soil type, vegetative cover, reclamation age and reclamation method. The rainfall plots were 35 feet long and were 10 feet wide at the Black Mesa Mine and 12 feet wide at the Navajo and McKinley Mines. The model was calibrated and validated separately for each mine using one-half the data for calibration and one-half for validation. Infiltration parameters were calibrated first. Each data set was subdivided by soil type and the infiltration parameters which best (by minimizing the sum of the squared errors) predicted the runoff response for each soil type were determined. Then, using the calibrated infiltration parameters, the same procedure was used to determine soil erodibility parameters. The model was then executed using the validation data to test the results. The results of the runoff and sediment yield tests of the Navajo Mine data set are shown in Figures 1 and 2, respectively. The figures present the results of using average infiltration and erosion parameters for each soil type. The model performed equally well with the calibration and validation data sets.

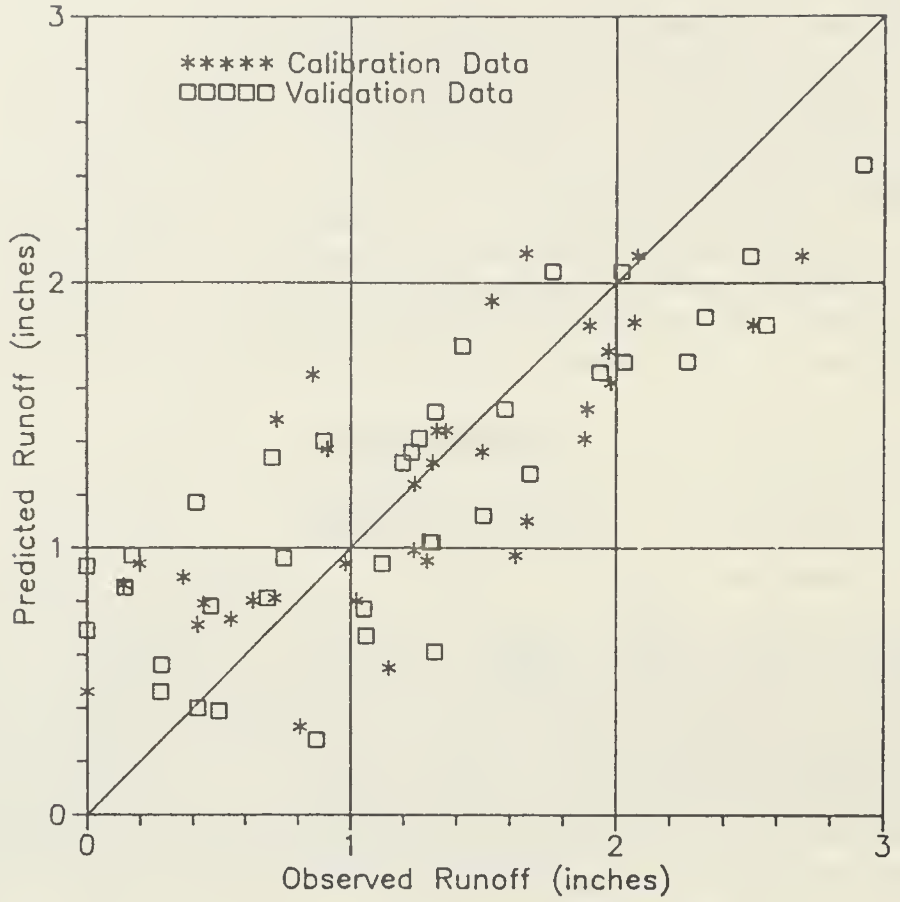

Figure 1. Navajo Mine predicted versus observed runoff.

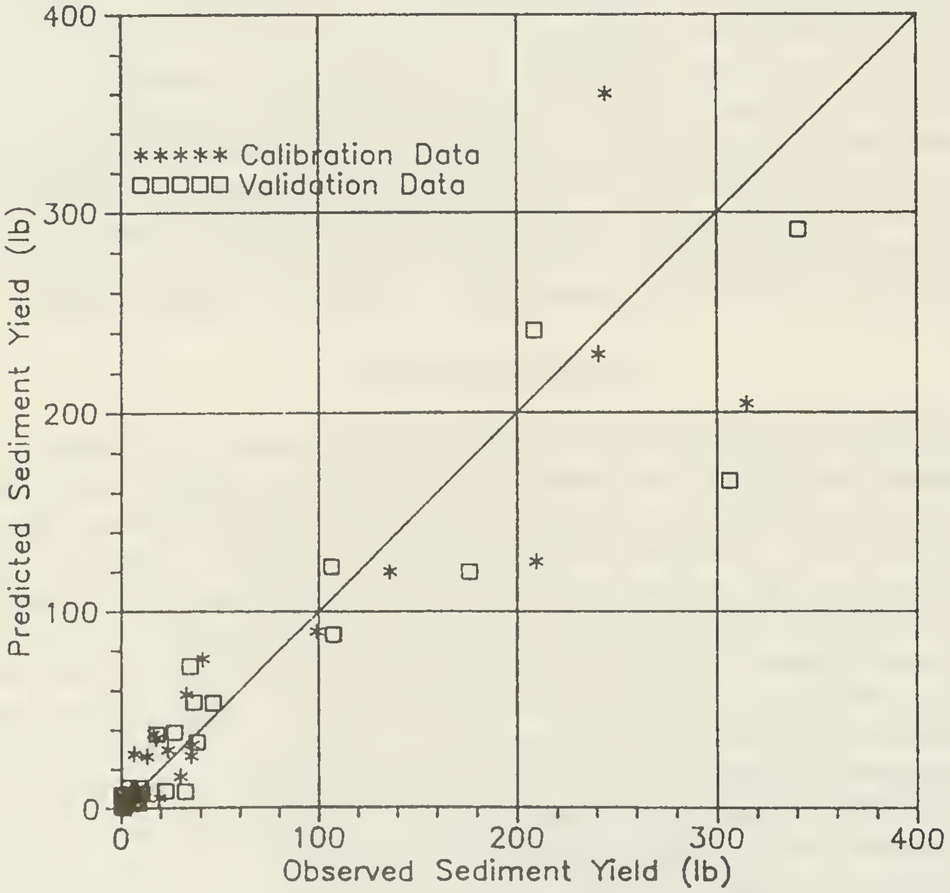

Figure 2. Navajo Mine predicted versus observed sediment yield.

PROCESS SIMULATION

Infiltration and Other Rainfall Abstractions

Short duration, high intensity summer thunderstorms dominate the runoff producing events in the semiarid west. Such events produce runoff when the rainfall intensity exceeds the rate at which the soil can absorb water. This rate is dependant on soil properties including porosity, antecedent soil moisture, capillary suction and hydraulic conductivity. The Green and Ampt infiltration equation is used in the EASI model. This equation uses the soil characteristics to predict the soil infiltration rate throughout a storm, thereby determining the amount of surface runoff.

Rainfall which is trapped by surface vegetation (interception) or which accumulates in surface depressions (depression storage) is also unavailable for runoff. Canopy cover includes shrubs and trees and ground cover includes grasses and other vegetation located on the ground surface. Depression storage includes natural depressions and manmade depressions (such as furrows and surface pitting). The aerial percentages of vegetative canopy and ground covers, the potential interception depth of the vegetation, and the average depression storage depth are required input to the EASI model.

Hillslope and Channel Flow Routing

Rainfall in excess of interception, infiltration and depression storage generates runoff on hillslopes. Within the EASI model, the flow is routed down the hillslope using a kinematic wave flow representation. The hillslope is treated as a planar surface of constant slope and roughness. The roughness of the hillslope is represented by the Manning flow resistance parameter. Hillslopes supply water to channels which in turn convey the water through the watershed. Channels are described by slope gradient, Manning flow resistance parameter and cross-section geometry. In the EASI model, channels can be either triangular, rectangular or trapezoidal in cross section. The kinematic wave flow representation is also used for flow routing in channels. Channel infiltration can also be significant in semiarid watersheds. This process is also simulated using the Green and Ampt infiltration equation.

Pond Flow Routing

Ponds store and retain runoff from upstream sources and also trap sediment. If the storage and outflow characteristics of a pond are known, the impacts on watershed hydrologic and sediment responses can be predicted. The user provides a table of pond storage and outflow versus water surface elevation. If the outflow characteristics of the pond are not known, the user may input primary and emergency spillway characteristics (including inlet elevations, pipe sizes, spillway lengths, etc.) and the program will determine the outflow characteristics internally. EASI uses the Modified Puls technique for routing flow through a pond.

Soil Erosion

Soil erosion occurs when soil particles are detached by either raindrop impact or by runoff forces. The susceptibility of soil to detachment is controlled by the cohesiveness, particle size, structure and type of the soil. For sandy soils which are not cohesive, detachment of individual particles is not required prior to transport. In that case the amount of erosion is limited by the capacity of flow to transport the soil. The EASI model requires detachment coefficients for raindrop impact and for surface flow. These detachment coefficients may be determined through calibration or can be estimated using soil type and other soil characteristics as a guide. Based on the hillslope soil and channel sediment characteristics along with rainfall intensities and runoff rates, the model determines the total amount of sediment available for transport in each part of the watershed.

Sediment Transport

In the EASI model, sediment is transported on hillslopes and in channels by size fraction (ten size gradations are used ranging from primary clay to gravel sizes) using the Meyer-Peter Muller sediment transport relationship. Because the amount of detached soil may be more or less than the amount of sediment which can be transported by the flow, the model can simulate supply limited or capacity limited sediment transport conditions. For example, a hillslope of a relatively cohesive, low detachability soil and with good vegetative cover may experience flows of high sediment transport capacity. The actual amount of sediment transported from this hillslope could be negligible because the soil characteristics and vegetation nearly eliminate erosion. Conversely, a channel composed of fine sand could receive flow from the previously described hillslope. Because the sand does not require detachment prior to transport, the amount of sediment available for transport greatly exceeds that which the channel flow can transport. In this case the channel flow will transport as much sediment as it physically can. A watershed comprised of such hillslopes and channels could produce large quantities of sediment even though the hillslopes are not eroding.

Ponds are often used to limit the amount of sediment leaving mined land. The amount of sediment trapped by a pond is determined by the settling velocity of the sediment, and the detention time of the runoff in the pond. The EASI program uses settling velocity - determined from the particle sizes - along with the pond storage and outflow characteristics to determine the trap efficiency of the pond. Because ponds are generally very efficient at trapping sediment, channel scour can occur downstream of a pond depending on the outflow characteristics of the pond and the sediment characteristics of the downstream channels. In such a case the pond may not significantly reduce the total amount of sediment produced by a watershed but change the sediment source from upstream of the pond to the channel downstream of the pond. The EASI program can be used to determine whether the pond will cause downstream channel erosion.

WATERSHED REPRESENTATION

Because watersheds can be comprised of hillslopes, channels and ponds, the EASI model treats these features as individual numerical model units. To simplify model input, a fourth unit - the subwatershed - is also included. By identifying the characteristics of each of these units and how the various units are connected, a complex watershed can be analyzed. Figure 3 shows a simple watershed as it would be represented within the EASI program. Water and sediment from hillslopes flow into channels, ponds and other hillslopes. Channels and ponds can receive flow from subwatersheds and from other channels and ponds. Extremely complex watersheds (in terms of land use, hillslope topography and the channel and pond network) can be simulated with this system.

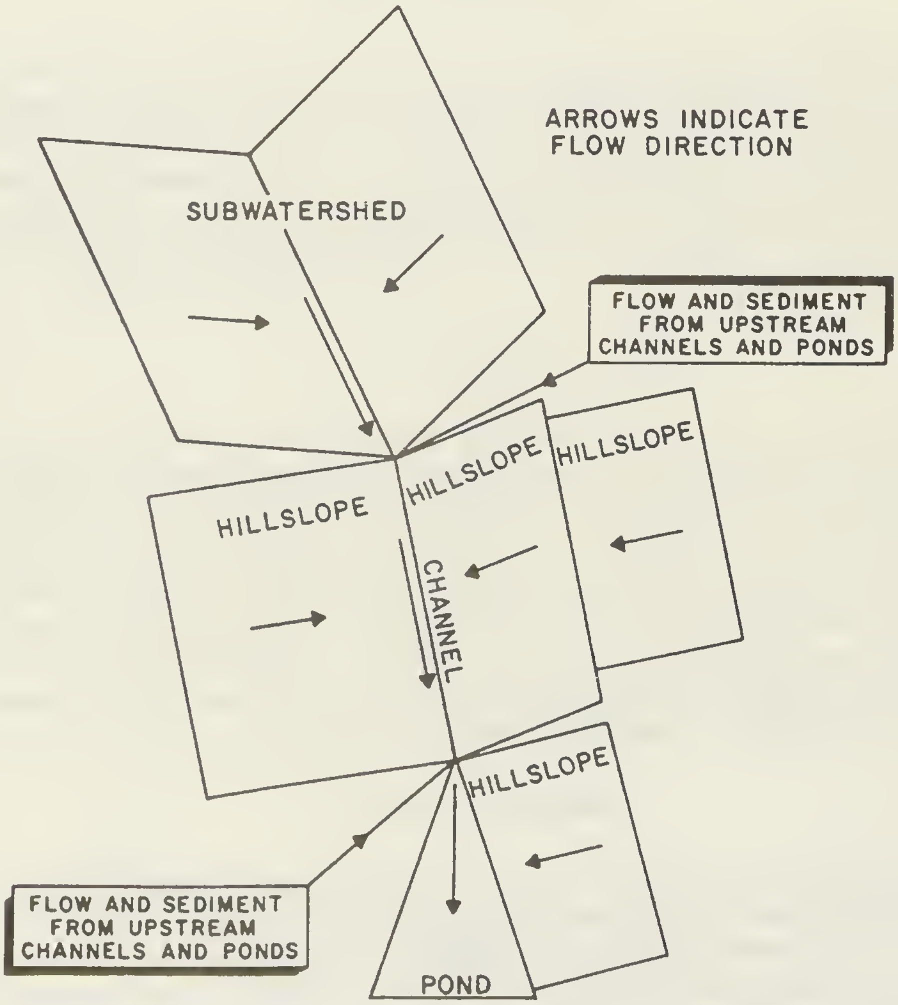
ARROWS INDICATE FLOW DIRECTION
SUBWATERSHED
FLOW AND SEDIMENT FROM UPSTREAM CHANNELS AND PONDS
HILLSLOPE
HILLSLOPE
HILLSLOPE
CHANNEL
HILLSLOPE
FLOW AND SEDIMENT FROM UPSTREAM CHANNELS AND PONDS
POND

Figure 3. Example watershed representation within the EASI model.

Hillslopes

Hillslopes are treated as constant gradient planes of individual soil, land use and management properties. By cascading hillslopes, variable hillslope gradients and variations in other hillslope properties are simulated. The sediment produced by one hillslope can be added to the supply of the next hillslope or deposited on the next hillslope. Hillslopes or groups of hillslopes supply water and sediment to channels and ponds.

Channels and Ponds

As shown in Figure 3, channel segments and ponds receive flow laterally from up to two hillslopes. Each channel segment or pond can also receive flow at the upstream end from up to three other channels and ponds and up to three subwatersheds. By allowing multiple connections at any channel or pond, a complex branching watershed can be simulated.

Subwatersheds

To simplify data entry, a fourth type of computer watershed unit is allowed. The subwatershed unit is comprised of two hillslopes and a channel. The unit is self-contained in that the subwatershed channel cannot receive flow from any other upstream unit. Other constraints of the subwatershed unit are that both hillslopes and channel must share the same soil properties and the two hillslopes must share vegetative and management properties. The hillslope gradients and lengths of a subwatershed remain independent. Subwatersheds are used to simulate the uppermost areas of a watershed and minor tributary areas.

USER INTERFACE

The previously described model is highly complex and sophisticated. For each hillslope, subwatershed, channel and pond a variety of input data are required. Therefore, for the model to be of value to people in charge of preparing and reviewing reclamation strategies, the numerical watershed model was combined with a user interface in order to simplify and streamline data entry. The user interface aids in the development of databases describing rainfall, soil characteristics and land treatment, generation and modification of computer watershed models, and produces clear and concise graphical and textual output.

Database Development

Prior to developing any complete watershed model, the user is required to develop databases of repeatedly used information. This information is required for the description of hillslope, subwatershed and channel units and includes rainfall events, soil characteristics and management practices. As more data become available the database is modified or expanded.

The rainfall database contains both hypothetical and user entered rainfall events. Within EASI, hypothetical rainfall events are described by the SCS Type II rainfall distribution. The user would use hypothetical events to predict watershed response to extreme storms (e.g. a 10-year recurrence 24-hour event) by identifying the total rainfall depth and the duration of the event. A user entered event contains data collected from a recording raingage and would be used when testing or calibrating the computer model. The user may also input other types of distributions as user entered events if the SCS Type II distribution is not applicable to the mine site.

The soil database contains soil descriptions (particle size distribution, detachment coefficients, infiltration coefficients, etc.) for individual soils. The user tailors this database to the local soil conditions and variability. Separate descriptions are be used for pre- and post-mine soils and for soils of different types (e.g. silty-clay versus a sandy-loam).

The management database contains the characteristics of the various management practices used at the mine. Management practices include revegetation and surface manipulation such as contour furrowing or surface pitting. Therefore, the management database includes canopy and ground cover percentages, interception potentials and depression storage amounts. The hillslope Manning flow resistance coefficient is also included in the management database because management practices impact the roughness and flow resistance properties of a land surface.

Watershed Model Generation

Once the databases have been developed the user can generate a watershed model. This is done in three steps: 1) the user creates units (hillslopes, subwatersheds, channels and ponds) and selects the appropriate rainfall, soil and management from the three databases. All three databases are required for hillslopes and subwatersheds, channel units require only a selection from the soil database and ponds do not use information contained in any database; 2) the user then identifies the topographic or geometric information for each unit. This includes hillslope areas, channel lengths, pond storage and outflow characteristics, and channel geometries; and 3) the user identifies the connections between the units. This is done by assigning an identification number to each unit and identifying the identification number of the downstream connecting unit.

Once the user selects the appropriate rainfall event, soil type and management practice from the appropriate data bases (from a screen menu), the majority of information describing a particular hillslope or subwatershed unit is identified. All that remains is the identification of unit topography or geometry (information readily available from topographic maps). Hillslope areas and gradients, and channel lengths and gradients, and pond volumes can be entered directly or they can be determined during watershed model generation using a topographic map and a digitizer.

Watershed Response

For each unit, a summary of the amount of runoff and sediment yield is produced. These results identify sediment sources and areas of deposition. The results files can be directed to the screen or printer. The resulting hydrographs are stored for every channel and pond unit. Hydrographs may be directed to the computer screen, pen plotters, dot matrix printers, and laser jet printers.

DISCUSSION

The propose of this project was to provide reclamation managers and regulatory personnel with the most accurate watershed hydrologic and sediment transport model available. The selected model accurately simulates a variety of watershed infiltration, runoff, erosion, and sediment transport processes using physically based relationships. The complexity of such a model dictates that a sophisticated user interface be employed to simplify and streamline the generation of the model.

The EASI model allows the user to evaluate pre-mine (background) conditions, to develop numerical models representing existing conditions, and to evaluate and plan future reclamation activities. The user can determine whether reclamation activities meet background sediment yield standards and whether ponds and other sediment control practices improve or adversely impact downstream channels.

ACKNOWLEDGEMENTS

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The views expressed in this paper are those of the authors and do not necessarily represent those of the sponsoring companies.

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Billings Symposium, 1990

HYDROLOGIC AND GEOCHEMICAL CHARACTERIZATION OF RECHARGE AND GROUNDWATER FLOW IN A RECLAIMED-COAL-MINED LAND, NORTHWESTERN COLORADO

Gregory M. Clark[1] and Robert S. Williams, Jr.[1]

ABSTRACT

Surface coal mining in northwestern Colorado has disturbed large areas of land and the underlying bedrock. During mining, the overburden and coal are removed, and the fragmented overburden (spoil) is placed back into the mine pit. This removal and replacement process can alter the hydrology of the area. At the Seneca Mine, a water-table aquifer has formed in the reclaimed-coal-mined land (RCML), and a spring, which is supplied by the water-table aquifer in the RCML, has formed at the base of the reclaimed slope.

Hydraulic and isotopic analyses indicate that during 1988, recharge to the aquifer in the RCML was from snowmelt and an underlying underburden aquifer. Mixing calculations based on oxygen and hydrogen isotope analysis from water samples collected in May 1988 indicate that between 53 and 63 percent of the recharge to the RCML aquifer came from the underburden aquifer.

The predominant ions in water samples collected from the aquifer in the RCML and from the associated spring were calcium, magnesium, and sulfate. The dissolved-solids concentration was about 2,800 milligrams per liter. Geochemical reaction simulations indicate that gypsum and epsomite are the primary minerals that affect water chemistry in the RCML. These minerals most likely occur as precipitated amorphous efflorescent salts and, prior to reclamation, are formed after the oxidation of pyrite and the dissolution of calcite and dolomite in spoil piles. The reaction model BALANCE indicated three feasible mixing simulations of soil water and underburden aquifer water in which 50 percent and 59 percent of the recharge to the aquifer in the RCML were from the underburden aquifer.

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INTRODUCTION

Surface coal mining disrupts large areas of previously undisturbed bedrock. During mining, the coal overburden is removed and deposited near the pit. After the coal has been removed, the fragmented overburden material (spoil) is placed back into the pit. The spoil then is recontoured, covered with topsoil, and seeded according to reclamation requirements.

Some characteristics of reclaimed-coal-mined land (RCML) are quite different from those of unmined land. In the geologic setting of northwestern Colorado, the RCML may be much more permeable than land in an unmined condition; thus, infiltration and percolation are enhanced. Because the surrounding undisturbed bedrock is relatively impermeable compared to the RCML, the materials in the RCML may begin to fill with water, which can result in the formation of an unconfined aquifer in the RCML. A spring forms at the base of the reclaimed slope as the water level in the aquifer rises to land surface.

The geochemical reactions in the RCML can be quite different from geochemical reactions in unmined land. Bedrock material is altered geochemically when it is removed from an environment that is generally deficient in oxygen and exposed to an oxygenated environment. This oxidized overburden material can contain large quantities of extractable salts that can dissolve rapidly in percolating soil water or when the material is placed below the postmine water table during reclamation. The breakup of bedrock material also increases the total area of exposed rock surface in the RCML; therefore, subsequent rates of weathering may increase. Consequently, dissolved-solids concentrations in mine-site water often are greater than those from pre-mine conditions (Groenewold and others, 1983, Powell and Larson, 1985).

Purpose and Scope

The primary objectives of this report are to: (1) Identify the sources of recharge to the aquifer in the RCML at a typical coal-mine site in northwestern Colorado by using hydrologic and geochemical information, and (2) characterize the primary geochemical reactions that affect the chemistry of water in the RCML environment at this coal-mine site. Conclusions in the paper are based on hydrologic, mineralogic, and water-quality data that were collected during the calendar year of 1988 from one site at the Seneca mine in northwestern Colorado.

Description of the Study Area

The study area is located at the Seneca coal mine in northwestern Colorado (fig. 1). More than 70 percent of the coal produced in Colorado is from this part of the State. The study area is located 20 miles west and 5 miles south of Steamboat Springs. Average yearly precipitation for the area measured over a 20-year period at Hayden, 10 miles northwest of the study area, is 16 inches (Enmap Corporation, 1981).

The study area lies along the southern flank of the Tow Creek anticline (fig. 1), a northeastwardly trending asymmetrical fold (Bass and others, 1955) that divides the area approximately in half. The study area is underlain by the lower member of the Cretaceous Williams Fork Formation. The lithology of this member consists of alternating beds of sandstone, siltstone, shale, and coal (Hildebrand and others, 1981). The three major coal seams currently (1988) being mined in the study area are the Lennox, the Wadge, and the Wolf Creek.

Study-site Description and Instrumentation

The Cow Camp study site is located in the southeastern part of the study area (fig. 1). Mining progressed through the site from 1983 to 1984, and the site subsequently was reclaimed from 1985 to 1986. Mining depth was to the base of the Wadge coal. An aquifer has developed within the RCML at the study site and discharges from a spring at the toe of the reclaimed slope. Figure 2 shows a diagram of the aquifer and spring in the RCML and the general lithology at the Cow Camp study site.

Instrumentation was installed at the study site during the summer and fall of 1987 (fig. 3). A drainage-type lysimeter was installed in the RCML at a depth of 8 feet to collect RCML recharge water. Water that percolated into the lysimeter was collected in a calibrated tank in an underground storage facility. A well was installed in the RCML to monitor water-table fluctuations in the aquifer. The total well depth was 55 feet and the bottom 40 feet of well casing was screened. The annulus of the well was gravel packed and the upper three feet of the annulus filled with cement grout. Another well was completed in a 10-foot-thick fractured sandstone aquifer that is stratigraphically below the Wadge coal. This well was 122 feet deep with well screen openings located only in the sandstone aquifer. A gravel pack was placed around the well screen, and bentonite pellets and bentonite slurry placed on top of the gravel pack to isolate the sandstone aquifer from any overlying aquifers. This sandstone aquifer (hereinafter referred to as the underburden aquifer) is separated from the base of the Wadge coal by a 10- to 12-foot-thick confining layer of interbedded sandstone, mudstone, and shale.

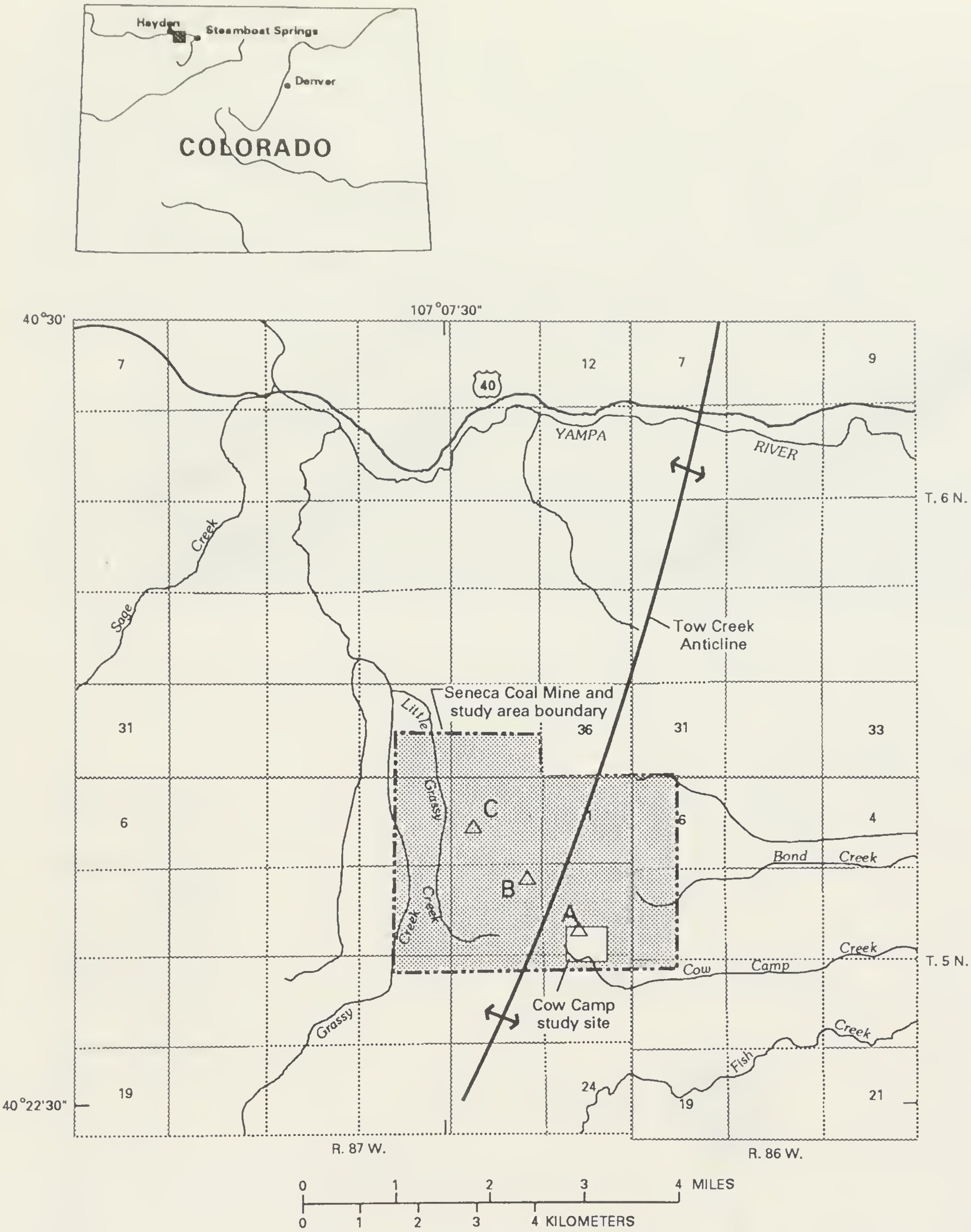

Figure 1. Location of the study area and the study site. $^{A}\Delta$, Spoil Sampling site and sample designation.

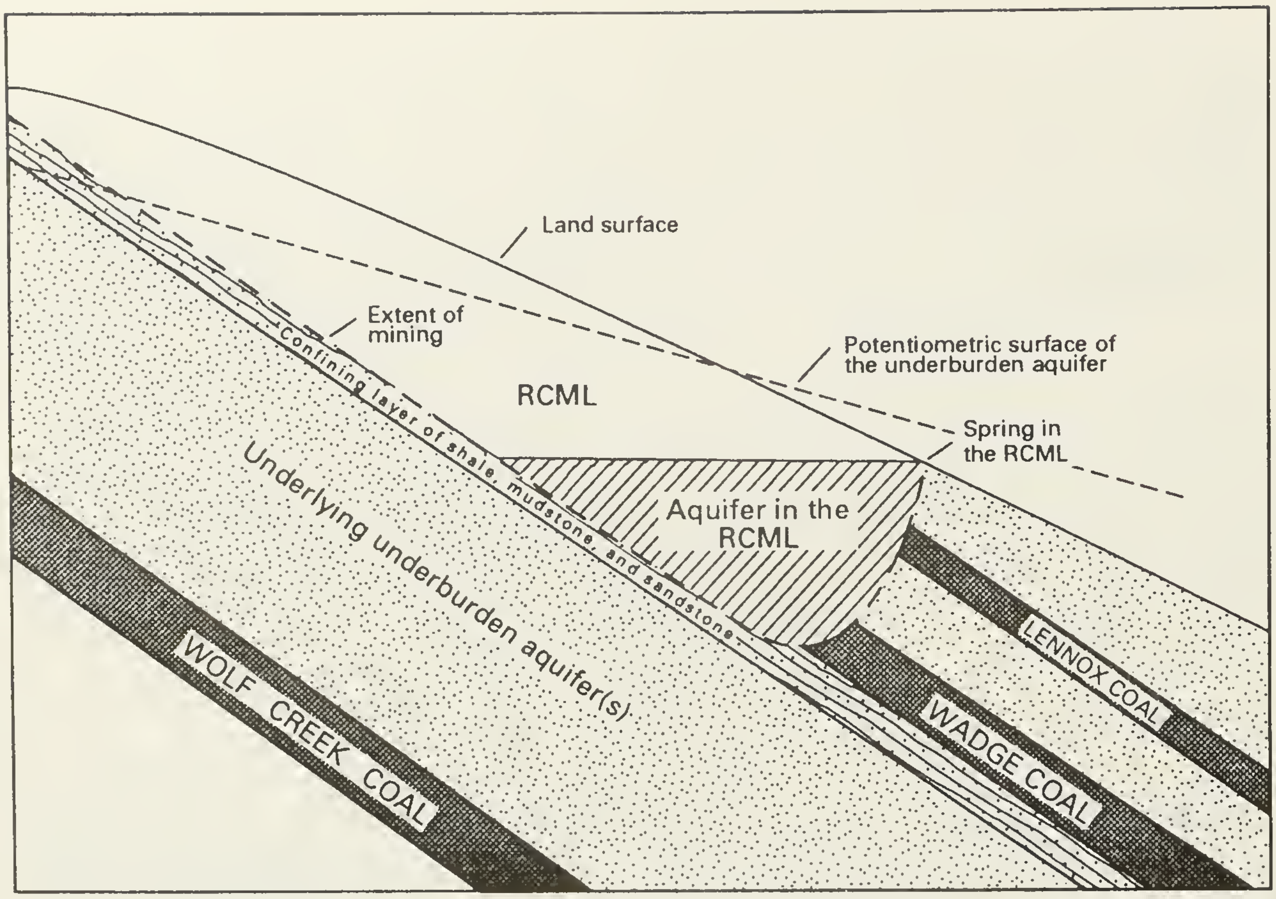
Land surface
Extent of mining
Potentiometric surface of the underburden aquifer
RCML
Spring in the RCML
Confining layer of shale, mudstone, and sandstone
Aquifer in the RCML
Underlying underburden aquifer(s)
LENNOX COAL
WADGE COAL
WOLF CREEK COAL

Figure 2. Diagram of reclaimed-coal-mined land (RCML) in which an aquifer and a spring have formed in the RCML.

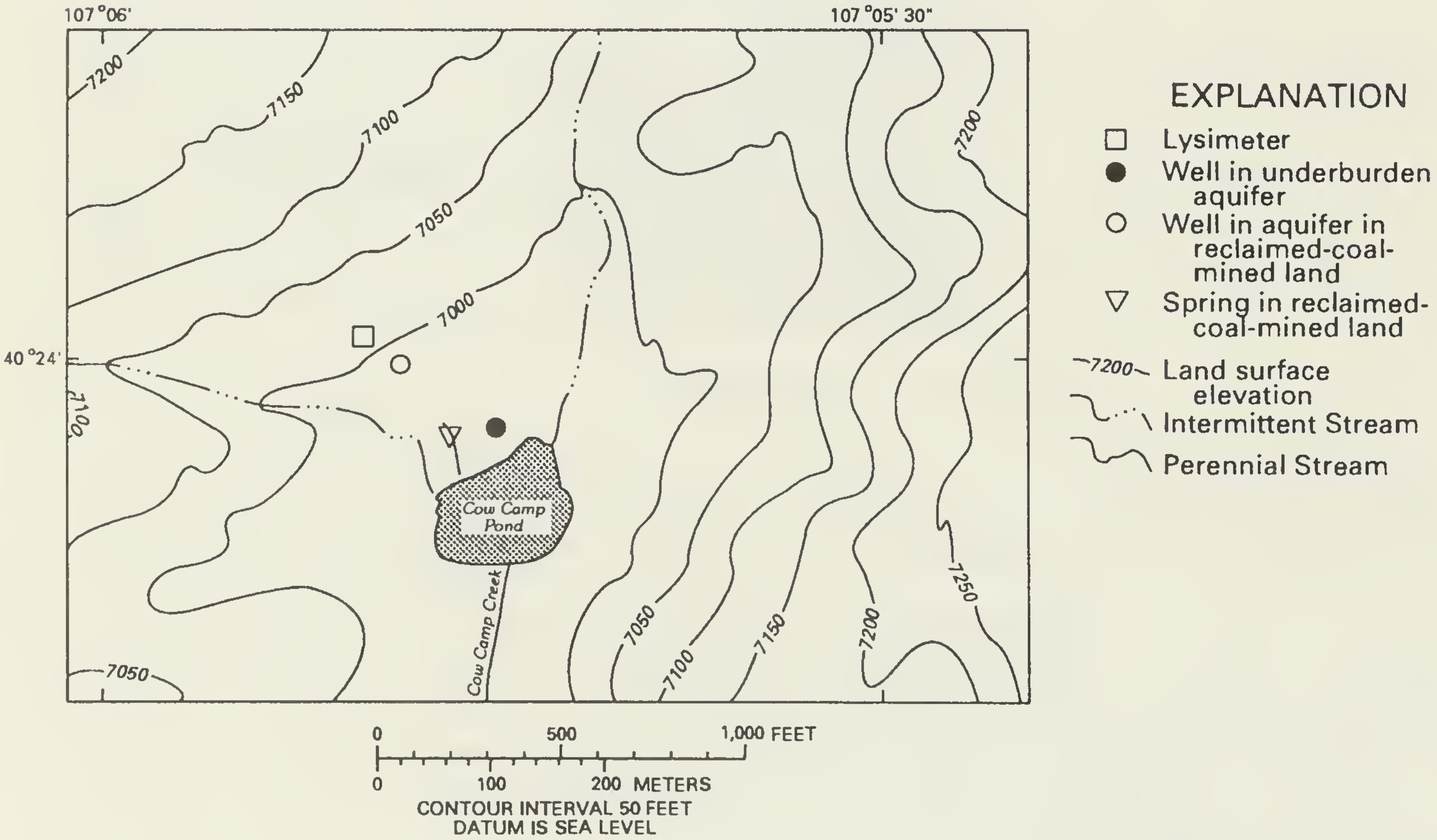

Figure 3. Data collection points at the Cow Camp study site.

SOURCES OF RECHARGE

Snowmelt and the underburden aquifer are two potential sources of recharge to the aquifer in the RCML. The Wadge coal has been completely removed from areas adjacent to the site and is not considered a potential source of recharge water to the RCML. Other sources of recharge, such as rainfall, seem to be insignificant. Recharge water to the RCML was collected in the lysimeter from mid-March until late June 1988; during the rest of the year, recharge to the lysimeter did not occur. The timing of water collection in the lysimeter indicates that the primary source of surface recharge to the RCML occurred as snowmelt during the spring months. Precipitation from rainfall in the summer probably was lost as evapotranspiration and did not reach the aquifer.

Recharge to the underburden aquifer occurs during spring snowmelt at the top of the Tow Creek anticline where the underburden aquifer crops out (Robson, U.S. Geological Survey and Stewart, Industrial Compliance Inc., written commun., 1989). The pressure head in the underburden aquifer well measured with a pressure gage reached a peak of 22.8 feet above land surface in early April 1988 following snowmelt and gradually declined until leveling off in August 1988 at about 13.5 feet above land surface.

Throughout 1988, the static water level in the underburden aquifer well was higher than the static water level in the aquifer well in the RCML, ranging from a maximum difference of 20.2 feet in April to a minimum difference of 11.6 feet in December. The higher water levels in the underburden aquifer throughout the year indicate that the hydraulic-head gradient and the potential for water movement was from the underburden aquifer to the overlying aquifer in the RCML. A confining layer between the two aquifers probably would prevent upward movement of water in an undisturbed condition; however, natural or man-induced disturbances to the confining layer such as faulting, blasting, or exploratory boreholes appear to have resulted in a hydraulic connection between the aquifers.

Isotope samples for oxygen-18 and deuterium analyses were collected in May 1988 from the lysimeter, the aquifer in the RCML, the spring in the RCML, and the underburden aquifer. Isotopes of oxygen-18 and deuterium have conservative properties in low-temperature ground-water systems and are virtually unaffected by chemical processes. These factors make these isotopes excellent tools for determining relative percentages of mixing in water derived from two different sources (Muir and Coplen, 1981). In figure 4, samples of $\delta^{18}O$ (oxygen-18/ oxygen-16 isotopic ratio) and δD (deuterium/hydrogen isotopic ratio) in samples

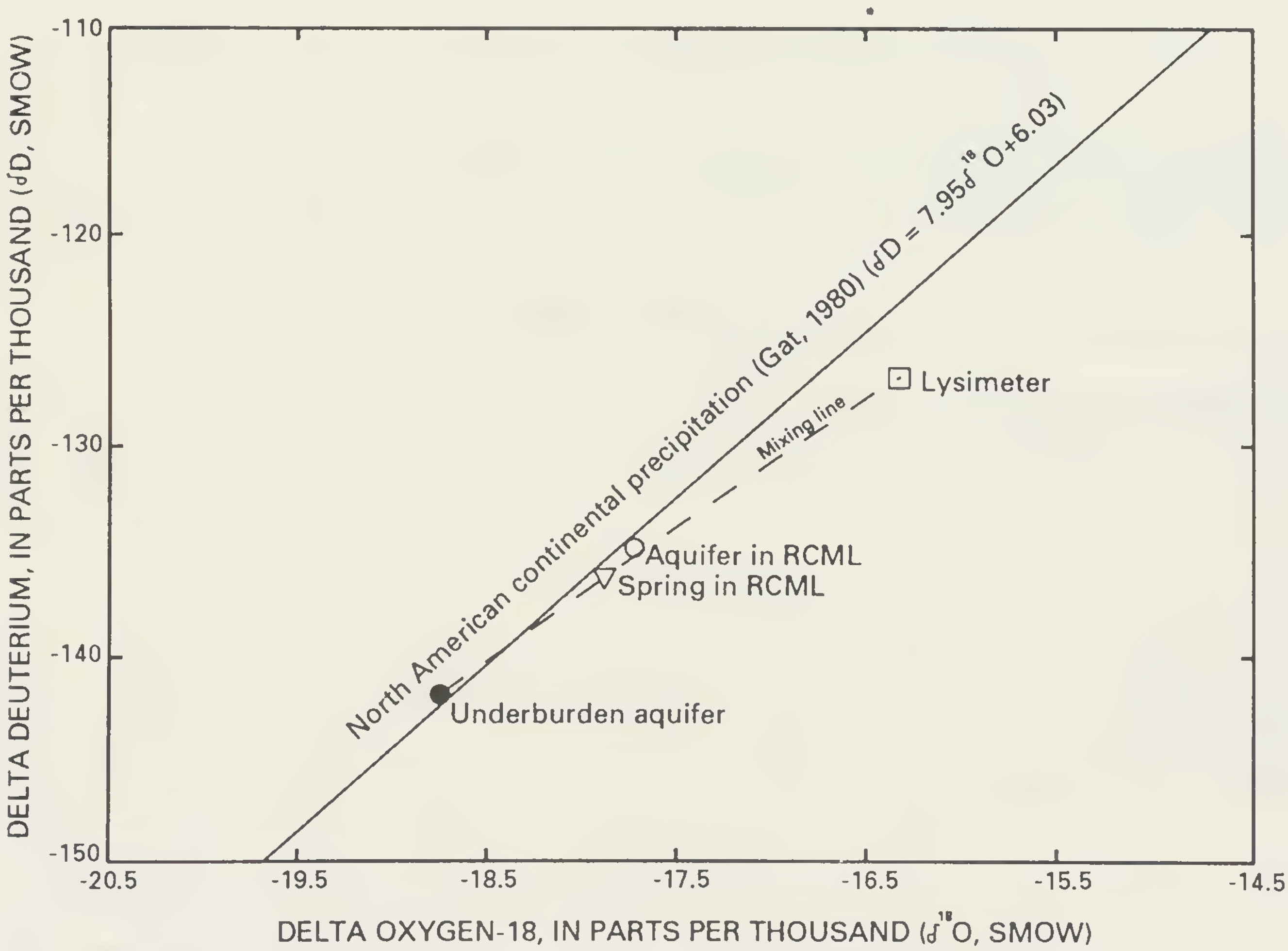

Figure 4. Stable-isotope ratios for water samples collected at the Cow Camp study site (RCML, reclaimed-coal-mined land; SMOW, standard mean ocean water).

collected at Cow Camp are compared to precipitation from North America as reported by Gat (1980). The North American continental precipitation line on figure 4 represents the isotopic composition of water samples from North America in which normal isotopic fractionation (precipitation of water vapor from clouds) has occurred. Water samples that have been subjected to evaporative processes or have undergone heating by rocks in geothermal systems may deviate from the continental precipitation line. The isotopic composition of water from the lysimeter falls somewhat below the water line indicating that some degree of heavy-isotope enrichment may have occurred due to evaporation.

The stable-isotope compositions of water from the aquifer and the spring in the RCML plot closely along the mixing line between the isotopic compositions of water from the lysimeter and from the underburden aquifer. The location of the water samples along the mixing line indicates that water from the aquifer in the RCML and the spring probably is a mixture of soil-water recharge (lysimeter water) and water from the underburden aquifer, and even if water collected in the lysimeter has undergone some degree of heavy-isotope enrichment due to evaporation, the part of water contributed to the RCML from the soil water has undergone the same degree of enrichment. Mixing calculations based on $\delta^{18}O$ and δD indicate that between 53 and 63 percent of the water from the aquifer and the spring in the RCML is from the underburden aquifer.

MINERALOGY OF SPOIL MATERIAL

Mineralogic analyses were made on spoil samples collected from the mine (table 1). Figure 1 shows the location of the three spoil piles sampled (A, B, and C). X-ray diffraction (Jackson, 1979) and sulfur-form analysis (Jackson and others, 1987) were done to identify prevalent minerals and to determine the percentage of sulfur in spoil samples. The cation-exchange capacity (Sandoval and Power, 1977) also was determined for the spoil samples. Although sulfate salts of gypsum and epsomite do not seem to be abundant minerals, they most likely are present in the spoil material as amorphous efflorescent salts and are not detected easily by X-ray diffraction. Epsomite and gypsum salts have been identified as amorphous precipitates at other surface coal mines in northwestern Colorado (McWhorter and others, 1975; Hounslow and others, 1978). The presence of pyrite was inferred from the sulfur-form analyses. Pyrite usually occurs as disseminated crystals or in concretionary forms and has been identified in the vicinity of the Seneca mine in numerous core samples from the Wadge coal and the Wadge overburden (Hounslow and others, 1978).

Table 1.--Mineral composition and sulfur-form analyses of spoil samples collected at the Seneca mine, in percent by weight

[Analyses by the North Dakota Mining and Mineral Resources Research Institute. The letter in the sample designation represents the spoil pile sampled and the number indicates separate samples within that pile; Organic sulfur was calculated as total sulfur minus sulfate sulfur minus pyritic sulfur; meq/100g, milliequivalents per 100 grams of spoil; <, less than]

Mineral or property	Sample designation								
	A1	A2	A3	B1	B2	B3	C1	C2	C3
Quartz	35	43	34	42	38	38	29	51	45
Kaolinite	34	26	36	34	33	17	50	21	32
Potassium feldspar	7	6	8	4	7	6	4	10	6
Plagioclase feldspar	5	8	4	7	9	6	3	5	3
Calcite	2	4	5	2	0	2	2	2	4
Dolomite	4	4	4	3	2	3	2	4	2
Gypsum	3	0	0	0	0	0	0	0	0
Illite/Muscovite	3	5	5	2	4	4	5	6	6
Chlorite	5	3	2	4	6	23	4	1	2
Mixed-layer clays	2	1	2	2	1	1	1	0	0
Total sulfur	.44	.24	.31	.45	.41	.48	.26	.24	.07
Sulfate sulfur	.09	<.01	<.01	.04	.04	.08	<.01	.02	.02
Pyritic sulfur	.20	.18	.25	.28	.27	.29	.21	.17	<.01
Organic sulfur (calculated)	.15	.05	.05	.13	.10	.11	.04	.05	.04
Cation-exchange capacity (meq/100g).	1.09	1.11	1.23	1.79	1.82	1.69	1.84	2.81	1.26

WATER CHEMISTRY

The chemical analyses of water collected at the Cow Camp study site in May 1988 are listed in table 2. The samples were analyzed by the U.S. Geological Survey National Water Quality Laboratory in Denver. Chemistries of water from the lysimeter and from the underburden aquifer were distinctly different. The lysimeter water had a dissolved-solids concentration of 3,360 mg/L (milligrams per liter) and was a calcium-magnesium-sulfate type. These three constituents accounted for 92 percent of the total mass of dissolved substances in the water collected from the lysimeter. Water from the underburden aquifer had a dissolved-solids concentration of 1,030 mg/L and was a sodium-bicarbonate-sulfate type. Sodium and bicarbonate accounted for 79 percent of the total mass of dissolved substances in the water from the underburden aquifer, whereas sulfate accounted for 21 percent of the total mass in solution. Water-quality samples from the aquifer and the spring in the RCML had dissolved-solids concentrations of about 2,800 mg/L and appeared to be a mixture of water from the lysimeter and the underburden aquifer.

Measurements of dissolved-oxygen and hydrogen sulfide concentrations were done onsite. Water samples from the RCML aquifer and RCML spring had measurable quantities of dissolved oxygen, whereas the underburden aquifer contained a small quantity of dissolved hydrogen sulfide. Redox could not be characterized accurately in the lysimeter water because of gas exchange that would have occurred in the collection container prior to sampling.

Table 2.--Selected water-quality information from water samples collected at the Cow Camp study site

[RCML, reclaimed-coal-mined-land; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; SiO_2, amorphous silica; H_2S, hydrogen sulfide; <, less than; ---, not measured]

Property or constituent	Source			
	Lysimeter	Underburden aquifer	Aquifer in RCML	Spring in RCML
Water temperature (°C)	13.5	10.7	10.7	10.0
pH (units)	8.0	8.4	7.1	7.1
Dissolved solids (mg/L)	3,360	1,200	2,860	2,760
Calcium (mg/L)	490	4.9	360	370
Magnesium (mg/L)	310	1.3	210	220
Sodium (mg/L)	55	340	160	150
Potassium (mg/L)	12	2.5	7.5	7.3
Iron (µg/L)	<12	29	22	22
Aluminum (µg/L)	10	<10	<10	<10
Alkalinity (mg/L as $CaCO_3$)	180	500	360	350
Sulfate (mg/L)	2,300	250	1,800	1,700
Chloride (mg/L)	19	6.9	14	13
Silica (mg/L as SiO_2)	18	9.5	12	9.8
Dissolved Oxygen (mg/L)	---	0.0	1.0	1.4
Dissolved H_2S (mg/L)	---	0.1	0.0	0.0

MINERAL-WATER REACTIONS

A number of geochemical reactions potentially can affect the chemical composition of RCML water. These reactions can include redox reactions, dissolution and precipitation reactions, hydrolysis of silicate minerals, and cation-exchange reactions.

Pyrite oxidation is an acid-producing reaction occurring in natural systems and can be represented by the equation:

$$4FeS_2+15O_2+14H_2O \text{-->} 4Fe(OH)_3+16H^++8SO_4^{2-}. \qquad (1)$$

The oxidation of 1 mole of pyrite in combination with the formation of iron hydroxide results in the production of 2 moles of sulfate and 4 moles of acid. Oxidation of pyrite occurs rapidly following removal of the overburden. Accelerated weathering experiments by Groenewold and others (1983) indicate that one cycle of complete water saturation and then complete drying is sufficient to oxidize reduced sulfur present in overburden material. Powell and Larson (1985) reported a 647-percent increase in pyrite oxidation following surface mining of coal in Virginia. Therefore, most of the pyrite in overburden material probably is oxidized and converted to sulfate prior to reclamation.

Acidic spoil water produced from pyrite oxidation is buffered when sedimentary rocks containing calcite and dolomite are present. The dissolution of these minerals is enhanced by the corrosive action of the acidic water. Buffering reactions of calcite and dolomite can be expressed as follows:

$$CaCO_3+H^+ \text{<-->} Ca^{2+}+HCO_3^- \qquad (2)$$

$$CaMg(CO_3)_2+2H^+ \longleftrightarrow Ca^{2+}+Mg^{2+}+2HCO_3^-. \quad (3)$$

The dissolution of the carbonate minerals will proceed until dissolved calcium and carbonate in the spoil water have reached an activity at which equilibrium with calcite and dolomite is established. When pyrite oxidation, represented by equation 1, is followed by a sufficient quantity of carbonate dissolution, represented by equations 2 and 3, a calcium, magnesium, sulfate, and bicarbonate water of approximately neutral pH is produced.

When drying follows wetting, amorphous efflorescent mineral salts can precipitate as water is evaporated. Successive periods of precipitation, followed by evaporative drying can produce large quantities of salt deposits in the upper few feet of a spoil pile or of the RCML soil profile. In water that is primarily affected by reactions represented by equations 1, 2, and 3, wetting followed by evaporative drying would result in the precipitation of calcite, gypsum, and epsomite salts. The precipitation of these three amorphous salts during evaporation of water can be expressed as follows:

$$Ca^{2+}+CO_3^{2-} \longleftrightarrow CaCO_3 \quad (4)$$

$$Ca^{2+}+SO_4^{2-}+2H_2O \longleftrightarrow CaSO_4 \cdot 2H_2O \quad (5)$$

$$Mg^{2+}+SO_4^{2-}+7H_2O \longleftrightarrow MgSO_4 \cdot 7H_2O. \quad (6)$$

Subsequent rainfall or snowmelt results in the redissolution of the newly precipitated mineral salts of calcite, gypsum, and epsomite. As the calcium concentration in the soil-water solution increases, calcite begins to precipitate as the solution becomes supersaturated with respect to calcite. Gypsum and epsomite can continue to dissolve until the aqueous solution becomes saturated with respect to those minerals. However, precipitating calcite functions as a sink for calcium, resulting in the dissolution of more gypsum and eventually a water with extremely large concentrations of dissolved sulfate. As a result, the RCML water has calcium, magnesium, and sulfate as the primary dissolved constituents.

Quartz and feldspars were identified by X-ray diffraction as the major minerals in the spoil material. However, in this system these minerals probably are not a major source of dissolved ions because of their relative insolubility in water. Small quantities of potassium, sodium, calcium, and silica may result from the hydrolysis of silicate minerals.

The primary source of clays at the Seneca mine is overburden shales, and the primary function of clays in the chemical evolution of coal-mine water is cation exchange. Kaolinite is the primary clay mineral in the spoil samples analyzed (table 1). Compared with other clay minerals, kaolinite has a relatively small cation-exchange capacity. At a pH of 7, kaolinite has a cation-exchange capacity of 3 to 15 milliequivalents per 100 grams of soil (Garrels and Christ, 1965). The cation exchange values for the spoil samples listed in table 1 have a mean value of 1.63 milliequivalents per 100 grams of soil.

Chlorite is another clay mineral identified in the spoil material that can affect the water chemistry of RCML water. Large concentrations of dissolved magnesium in coal-mine water have been attributed to weathering of chlorite, as reported by Senkayi and others (1981) and Naftz (1988). The equation for a reaction in which chlorite is weathered to form talc is:

$$Mg_3(OH)_6(Mg_2Al)(AlSi_3)O_{10}(OH)_2+6H^+ \longrightarrow \quad (7)$$
$$3Mg^{2+}+6H_2O+(Mg_2Al)(AlSi_3)O_{10}(OH)_2.$$

Further weathering of the talc can occur and release additional magnesium ions.

GEOCHEMICAL REACTION SIMULATION

The activities of dissolved chemical constituents and the saturation indices (SI) for plausible mineral sinks or sources in RCML water were determined by using the U.S. Geological Survey computer program WATEQF (Plummer and others, 1976). The SI (dimensionless) is the logarithm of the ion-activity product (IAP) divided by the equilibrium constant (K) at 25 degrees Celsius for a specific mineral-water interaction:

$$SI=\log(IAP/K). \quad (8)$$

A negative SI indicates that the water is undersaturated with respect to the mineral and if present, on the basis of thermodynamic data, the mineral should be dissolving. If the SI is positive, the water is supersaturated with respect to the mineral, and the mineral should precipitate. An SI value at or near zero indicates a condition near equilibrium. Selected SI values for the water collected at the Cow Camp study site are listed in table 3. An SI for epsomite was not calculated because of a lack of established free-energy data.

Table 3.--Saturation indices for selected mineral phases

[Positive index, mineral will tend to form; negative index, mineral will tend to dissolve; RCML, reclaimed-coal-mined land]

Mineral (saturation index)	Source			
	Lysimeter	Underburden aquifer	Aquifer in RCML	Spring in RCML
Calcite	0.718	-0.072	0.049	0.015
Dolomite	1.479	-.558	.056	-.034
Gypsum	-.015	-2.419	-.162	-.161
Halite	-7.652	-7.201	-7.300	-7.354

The degree of mineral-water interaction that occurs as ground water moves through the RCML environment was quantified by using the U.S. Geological Survey computer program BALANCE (Parkhurst and others, 1982). Using the solution composition at two points along a flow path and a set of mineral phases, the program provides a set of mineral-water reactions that could occur to produce the end-point solution composition. The general equation is:

$$\text{Initial solution composition} + \text{Reactant minerals} \rightarrow \text{End-point solution composition} + \text{Product minerals.} \quad (9)$$

BALANCE also can simulate mixing of two types of water to produce an end-point solution composition. A general equation for this reaction is:

$$\alpha_1(\text{Initial solution 1}) + \alpha_2(\text{Initial solution 2}) + \text{Reactant minerals} \rightarrow \text{End-point solution composition} + \text{Product minerals} \quad (10)$$

where α_1 and α_2 represent the relative contributions to the end-point solution composition.

Major-ion and trace-metal analyses in table 2 were used as input data for WATEQF and BALANCE. The reactant and product mineral phases used for the models were selected from table 1 and from mineralogic data in Hounslow and others (1978).

Recharge from Snowmelt

The geochemical reactions that occur when snowmelt percolates into the RCML were simulated by using BALANCE. Infiltrating snowmelt was used as the initial solution composition, and although snowmelt has a finite chemical composition, for the purposes of the simulations, the snowmelt was assumed to be free of dissolved solids. The chemistry of the lysimeter water was used to represent the end-point solution composition. A set of reaction simulations representing mineral-water reactions that could produce the lysimeter water chemistry are listed in table 4. Reaction simulations 4, 5, and 7 do not seem to be feasible for water that has been collected in the lysimeter. The measured pH of the lysimeter water is 8.0 (table 2). However, the pyrite oxidation represented in reaction simulations 4, 5, and 7 would produce acidic lysimeter water. The carbonate dissolution in reaction simulations 4, 5, and 7 is not sufficient to buffer the acid that would be produced from the pyrite oxidation. Reaction simulation 2 indicates a substantial quantity of plagioclase feldspar dissolution and because of this, reaction simulation 2 also can probably be eliminated. Because they are primary silicate minerals, the feldspars are relatively insoluble in water. The feldspars may contribute minor quantities of potassium, sodium, and calcium to ground water; however, feldspars probably are not contributing large quantities of dissolved solids to RCML water.

Reaction simulations 1, 3, and 6 when used in combination or alone probably represent feasible mineral-water interactions that occur during movement of snowmelt to the lysimeter. Of these three reaction simulations, simulation 1 indicates calcite precipitation, and simulations 3 and 6 indicate calcite dissolution. Results from WATEQF indicate that the lysimeter water is saturated with respect to calcite; however, whether a net precipitation or dissolution of calcite has occurred is difficult to determine. Reaction simulation 6 also indicates the oxidation of pyrite; however, in this simulation, a sufficient quantity of calcite is dissolved to effectively buffer the addition of acid and still maintain a pH in the neutral range.

Table 4.--Results of mass-balance modeling for shallow recharge using snowmelt as the initial solution composition and lysimeter water as the end-point solution composition

[Values are in millimoles per kilogram of water; A positive value indicates dissolution of the phase; a negative value indicates formation of the phase; ---, indicates that the phase was not used in the model]

Mineral	Reaction simulation						
phase	1	2	3	4	5	6	7
Calcite	-4.0300	-4.0100	1.6450	-23.0800	2.5000	2.5000	2.5000
Dolomite	3.0000	---	---	12.7900	---	---	---
Gypsum	13.7650	15.4800	10.8525	21.7629	8.9729	10.2350	10.2350
Epsomite	10.2550	8.5400	13.1675	---	12.7900	13.2550	---
Chlorite	---	.8500	---	---	---	---	2.6510
Plagioclase	---	2.6600	.5000	2.6571	2.6571	---	---
Potassium Feldspar	.3000	.3000	.3000	.3000	.3000	.3000	.3000
Kaolinite	-.1500	-1.0000	-.1495	-.1500	-.1500	-.1500	-2.8010
Quartz	-.3000	-5.8700	-1.0100	-4.0200	-4.0200	-.3000	-2.9510
Halite	.5400	.5400	.5400	.5400	.5400	.5400	.5400
Pyrite	---	---	---	1.1286	1.1286	.2650	6.8925
Goethite	---	---	---	-1.1286	-1.1286	-.2650	-6.8925
Carbon dioxide	.5300	6.5100	.8550	---	---	---	---
Oxygen	---	---	---	4.3309	4.3309	1.0925	25.9456
Cation exchange	.9300	---	.7555	---	---	.9300	.9300

Mixing of Soil Water and Underburden Aquifer Water

The geochemical reactions that occur when soil water (water from snowmelt) and water from the underburden aquifer mix to form water from the RCML spring also were simulated by using BALANCE. The chemistry of the lysimeter water and of the water from the underburden aquifer were used as the initial solution compositions, and the chemistry of the water from the RCML spring was used as the end-point solution composition. Mixing results are listed in table 5.

Table 5.--Results of mass-balance modeling for mixing by using water from the lysimeter and the underburden aquifer as initial solution compositions and water from the spring in the RCML as the end-point solution composition

[Values are in millimoles per kilogram of water; A positive value indicates dissolution of the phase; a negative value indicates formation of the phase; -- indicates phase not used in the reaction model]

Relative contribution	Reaction simulation			
or mineral phase	1	2	3	4
Contribution from soil water.	0.66	0.50	0.50	0.41
Contribution from the underburden aquifer.	.34	.50	.50	.59
Calcite	0.6383	0.9640	-3.2231	0.2000
Dolomite	---	---	2.0936	---
Gypsum	.4623	1.5447	3.6382	3.1242
Epsomite	.5092	2.0936	---	2.5632
Chlorite	.0166	---	---	.8000
Plagioclase	---	---	---	---
Potassium Feldspar	-.0331	.0040	.0040	.0254
Kaolinite	---	-.0020	-.0020	-.1327
Quartz	-.0389	-.0741	-.0741	-.1040
Halite	-.0539	---	---	.0312
Pyrite	---	.3498	.3498	---
Goethite	---	-.3498	-.3498	----
Carbon dioxide	.9920	---	---	.3782
Oxygen	---	1.3118	1.3118	---
Cation exchange	---	1.0014	1.0014	1.5813

Reaction simulation 1 almost certainly does not represent mixing of soil water and water from the underburden aquifer. This simulation indicates that precipitation of halite and potassium feldspar occur. Results from WATEQF indicate that halite is undersaturated in all of the water samples and, therefore, would not precipitate. It also is unlikely that potassium feldspar would be precipitating in the RCML environment. Figure 5 represents a stability diagram for selected silicate minerals. The locations of the water samples on the stability diagram indicate that potassium feldspar would not be a stable mineral under the given conditions whereas kaolinite would appear to be stable. Any of the BALANCE reaction simulations in which greater than 50 percent of the water from the RCML spring was contributed from soil water required the precipitation of halite and potassium feldspar.

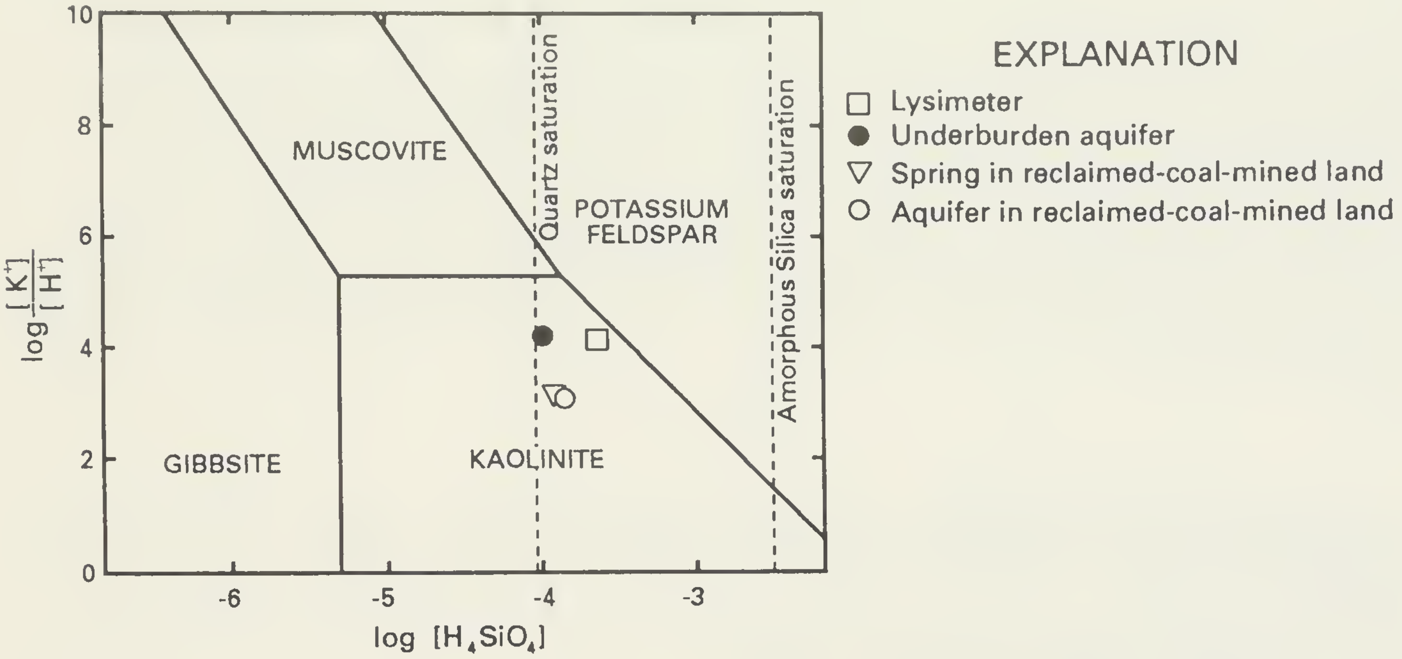

Figure 5. Relation of water samples collected at the Cow Camp study site within the stability fields of muscovite, gibbsite, kaolinite, and potassium feldspar at 25 degrees Celsius and one atmosphere (modified from Van Breeman and Brinkman, 1978).

Reaction simulations 2, 3, and 4 represent feasible solutions of possible mixing of soil water and water from the underburden aquifer to form water with the chemical characteristics of the RCML spring. All three of these simulations closely agree with the relative mixing ratio between soil water and water from the underburden aquifer calculated from the stable-isotope data.

TRANSFERABILITY OF THE FINDINGS

The methods and concepts used in this investigation can be used to evaluate other mined areas in northwestern Colorado. However, such evaluations would require the collection of data in the area of interest or concern. The estimates of quantities of water recharged to the RCML from the underburden aquifer and from soil water, as indicated by isotope analysis and the computer models, are based on only one set of samples collected at one site in May of 1988. The relative quantity of recharge from each source at the Cow Camp site and at other sites may vary as hydrologic conditions change.

SUMMARY

An unconfined aquifer has developed within the reclaimed-coal-mined land (RCML) following surface coal mining at the Seneca mine in northwestern Colorado. This aquifer discharges as a perennial spring at the toe of the reclaimed slope. Snowmelt moving downward and water moving upward from the underburden aquifer have been identified as two potential sources of recharge to the aquifer in the RCML. Analyses of stable isotopes from water samples collected in May of 1988 indicate that between 53 and 63 percent of the water in the aquifer in the RCML was derived from the underburden aquifer.

Water samples from the aquifer and the spring in the RCML had a dissolved-solids concentration of about 2,800 milligrams per liter and a chemical composition that seemed to be a mixture of soil water (water from snowmelt) and water from the underburden aquifer. The predominant ions in water samples from the aquifer and from the spring in the RCML were calcium, magnesium, and sulfate.

Pyrite oxidation, carbonate dissolution, and precipitation of efflorescent amorphous salts during evaporation of water occur in spoil piles prior to reclamation. Pyrite oxidation probably is a more important reaction in spoil piles prior to reclamation, where it can yield large quantities of dissolved sulfate. Pyrite oxidation was not an important reaction in RCML after reclamation as indicated by the near neutral pH of water collected from the lysimeter, the aquifer in the RCML, and the spring in the RCML. Pyrite oxidation, concurrent with the dissolution of carbonate minerals and subsequent evaporation of water, results in the precipitation of amorphous efflorescent mineral salts of gypsum, epsomite, calcite, and others. After reclamation, water moving through the RCML redissolves the precipitated salts, which results in an increase in dissolved-solids concentrations.

By using the U.S. Geological Survey computer programs WATEQF and BALANCE, feasible reaction simulations were developed for shallow recharge of snowmelt water to form the chemistry of water from the lysimeter (soil water), and for mixing of soil water and underburden-aquifer water to form the chemistry of water from the RCML spring. The dissolution of amorphous salts of gypsum and epsomite probably are the primary reactions contributing to the chemistry of RCML water. Weathering of carbonate and clay minerals, hydrolysis of silicate minerals, and cation-exchange reactions are other reactions that can affect the chemistry of RCML water. Feasible reaction simulations were developed in which 50 percent and 59 percent of the recharge water to the aquifer in the RCML was from the underburden aquifer.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

GROUND-WATER CHANGES NEAR MONTANA COAL MINES

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ABSTRACT

Hydrologic conditions near surface coal mines in southeastern Montana are being monitored because the coal beds are the most accessible and widely used aquifers of the region. Mining has thus far affected water levels in alluvium only locally, if at all. Water levels in coal-bed aquifers are being lowered within about 2 miles of active mines near Colstrip. As mine pits are backfilled with spoil, hydrostatic pressures in both the spoil and adjacent aquifers are recovering toward pre-mining levels. At Decker, a potentiometric depression has formed over an area more than 5 miles wide and 15 miles long, caused by converging of drawdowns created by 3 mines. At all mines, water-level declines clearly illustrate the influences of directional permeabilities and hydrologic boundaries.

As pits are being backfilled, spoils are rapidly becoming resaturated by inflow from undisturbed aquifers, laterally at all mines, and vertically where conditions are appropriate. It is hypothesized that pre-mining non-plugged drill holes allow vertical flow. In the resaturation process, strongly increased concentrations of dissolved solids (primarily calcium, magnesium, sodium, and sulfate) are evolving. The initial chemical quality of spoils water is highly diverse because of the variable distribution of soluble salts in the spoils. As ground-water flow in the spoils continues, trends are becoming apparent. Some sites are currently showing increasing concentrations where surface recharge introduces dissolved solids faster than they are flushed from the system. Other sites show decreasing trends where new salts are not introduced by recharge. In these cases, chemical quality of spoils water may approach pre-mining quality within the predictable future.

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INTRODUCTION

Energy is not the only resource that southeastern Montana coal can provide. The coal beds, because of their generally fractured characteristics and broad areal continuities, are commonly the most accessible and widely used aquifers of the region. In this semi-arid climate, many inhabitants are almost totally dependent upon ground water for stock and domestic supplies and in many places they obtain it from coal beds that will be removed by mining. Concerns logically arise over the possible impacts of mining upon water supplies that are vital for agriculture.

More than 32 billion tons of lignite and subbituminous coal are present within Montana's portion of the Fort Union Coal Region (Matson and Blumer, 1974). Twenty-six coal beds have been identified there, having thicknesses between 3 feet and 75 feet, and underlying almost 800 thousand acres. Thus far, the subbituminous beds have been the primary objects of development because of thickness, areal persistence, low-sulfur content (generally less than 1 percent), and shallow depth. Although coal has been mined in the region by individuals and small concerns for many years, most of these operations were underground mines that had little noticeable effect on the land or water. Larger scale surface mining has now come to the subbituminous fields. Since 1968, six surface mines have been opened and numerous others are in planning stages.

The need for ground-water information became extreme with the advent of large-scale surface mining, so the Montana Bureau of Mines and Geology began programs of hydrologic study near the Rosebud, Big Sky, and Decker mines (Figure 1). Many important hydrologic aspects of surface mining have been learned and the knowledge has been applied extensively by State and Federal regulators on decisions regarding leasing, data standards, mine permits, methods, and reclamation. Along with the knowledge, a network of strategic observation wells evolved and a sophisticated, coal-field-specific, computerized data system was generated. The data file in that system contains water-level and -quality data, in many cases covering 15 or more years of record.

This report presents selected examples and interpretations of monitoring results at and near the Rosebud, Big Sky, and Decker mines in southeastern Montana. A much greater amount of data has been collected than is reported herein and can be seen at, or obtained from the Bureau of Mines and Geology's Billings office.

Appreciation is extended to the U.S. Bureau of Land Management and the Montana Coal Board for funding and for cooperative help on technical aspects of mining hydrology, and to the Rosebud Conservation District for administrative support in recent years. Thanks are also extended to Western Energy Company, Peabody Coal Company, Kiewit Mining and Engineering Co. and Decker Coal Co. for long-standing access to their properties and for sharing of data.

This reporting of Montana Bureau of Mines and Geology data and interpretations is not made in disregard of monitoring efforts by mining companies of the area. Each company painstakenly monitors hydrologic aspects of its own activities and reports appropriate data to the Montana Department of State Lands. Exchange and comparison of data between the Bureau, the Department, and the companies is a long-standing tradition that adds credibility and cohesiveness to all of the information.

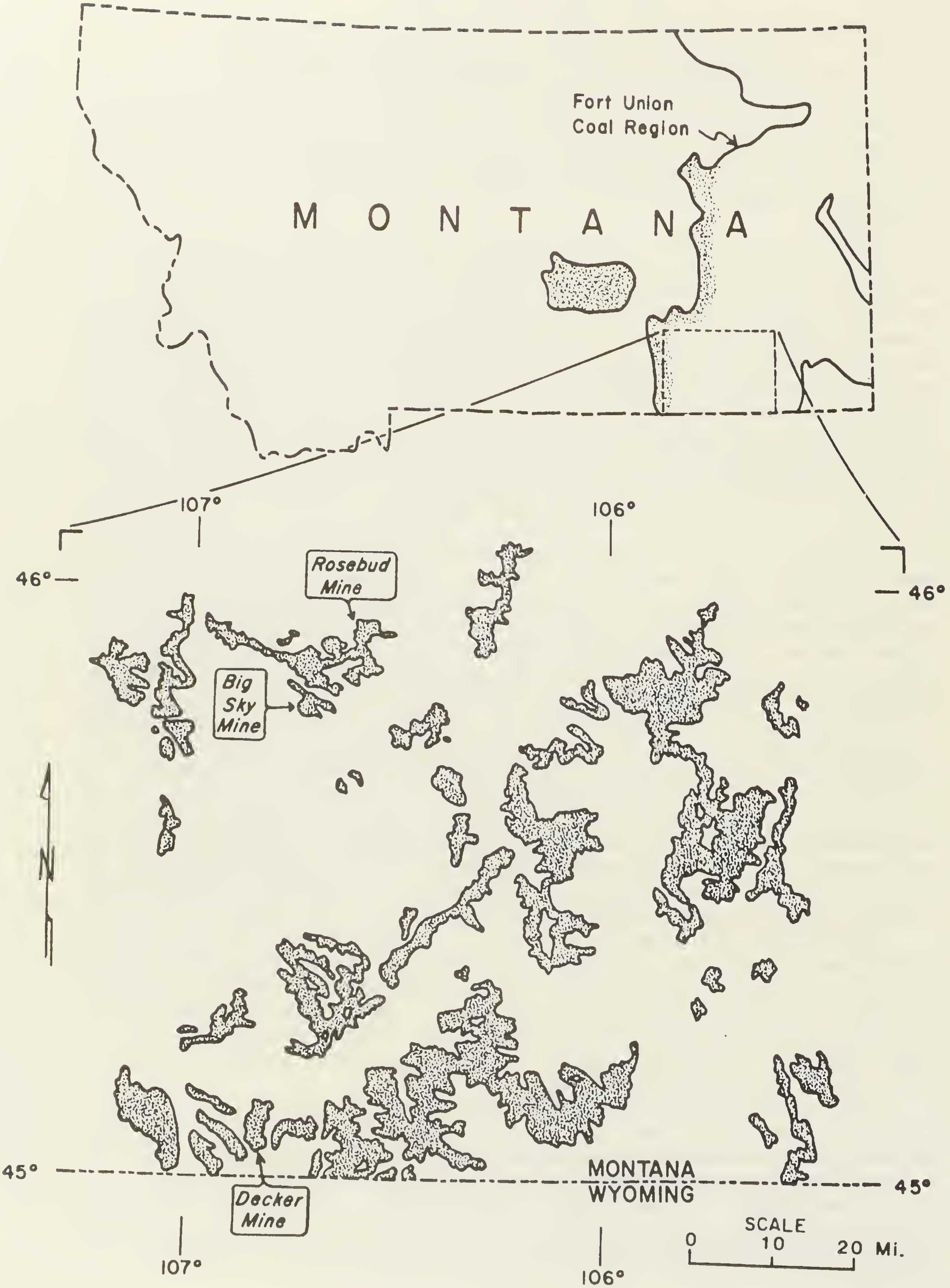


Figure 1—The Rosebud, Big Sky, and Decker mine areas are in the subbituminous portion (stippled pattern) of the Fort Union coal region.

Water Levels

Mine-inflow rates and associated water-level or hydrostatic-pressure declines are influenced greatly by the positions of mines within the ground-water flow systems. Mine cuts that begin along aquifer outcrops stress the flow systems very slowly. Such pits gradually change aquifer boundaries, and hydrostatic- pressure changes are similarly gradual. Inflow to those pits consists mostly of intercepted ground water, and the inflow rates are generally negligible. As mining proceeds, pits are expanded or moved too slowly to induce significant inflow from ground- water storage. Hydrostatic-pressure declines associated with such gradual releases from storage are also very gradual and commonly are not detectable more than about 2 miles away. Mines near Colstrip are examples of gradual outcrop displacement that creates gradual hydrogeologic effects.

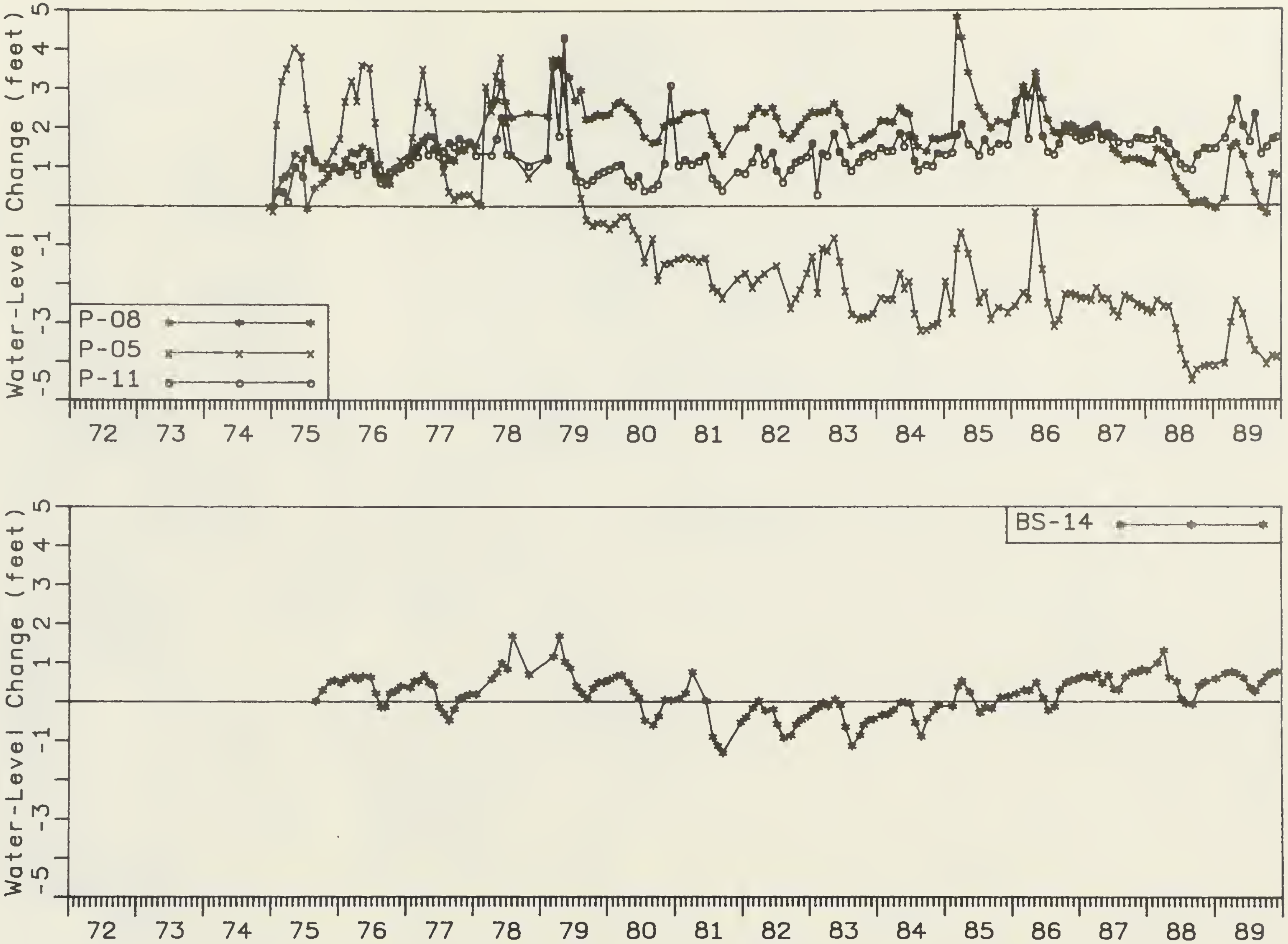
In contrast, mines that operate between the outcrops of coal-bed aquifers (such as near Decker) create relatively rapid and dynamic changes in the ground-water system. Coal beds there have hydraulic conductivities similar to others in the region, but lie in a somewhat unique geological setting where parallel faults, uplifted recharge areas, and a regional discharge area control ground-water flow. Effects of mining there have been dramatic and widespread. Drawdowns such as those described for the Decker area would be unlikely over much of the region. They should be expected, however, along its western edge where faulting and uplift have occurred, and will be particularly important where cumulative effects of multiple mines are a concern.

The rapidity with which mine spoils become resaturated cannot be explained only be recharge from infiltration of rainfall and snowmelt. Lateral flow from adjacent undisturbed aquifers is an obvious and predictable mode of recharge, given reasonable understanding of geology and ground-water flow in a mine area. Upward flow from deeper aquifers has traditionally been thought of as leakage through poorly permeable underlying mine floors, and has been given little significance. Evaluations of data presented later in this paper show that hydraulic continuity exists between mined lands and deeper aquifers, and that vertical flow to spoils occurs in at least one location. An explanation is proposed that such flow occurs by way of unplugged exploration holes drilled in search of more coal.

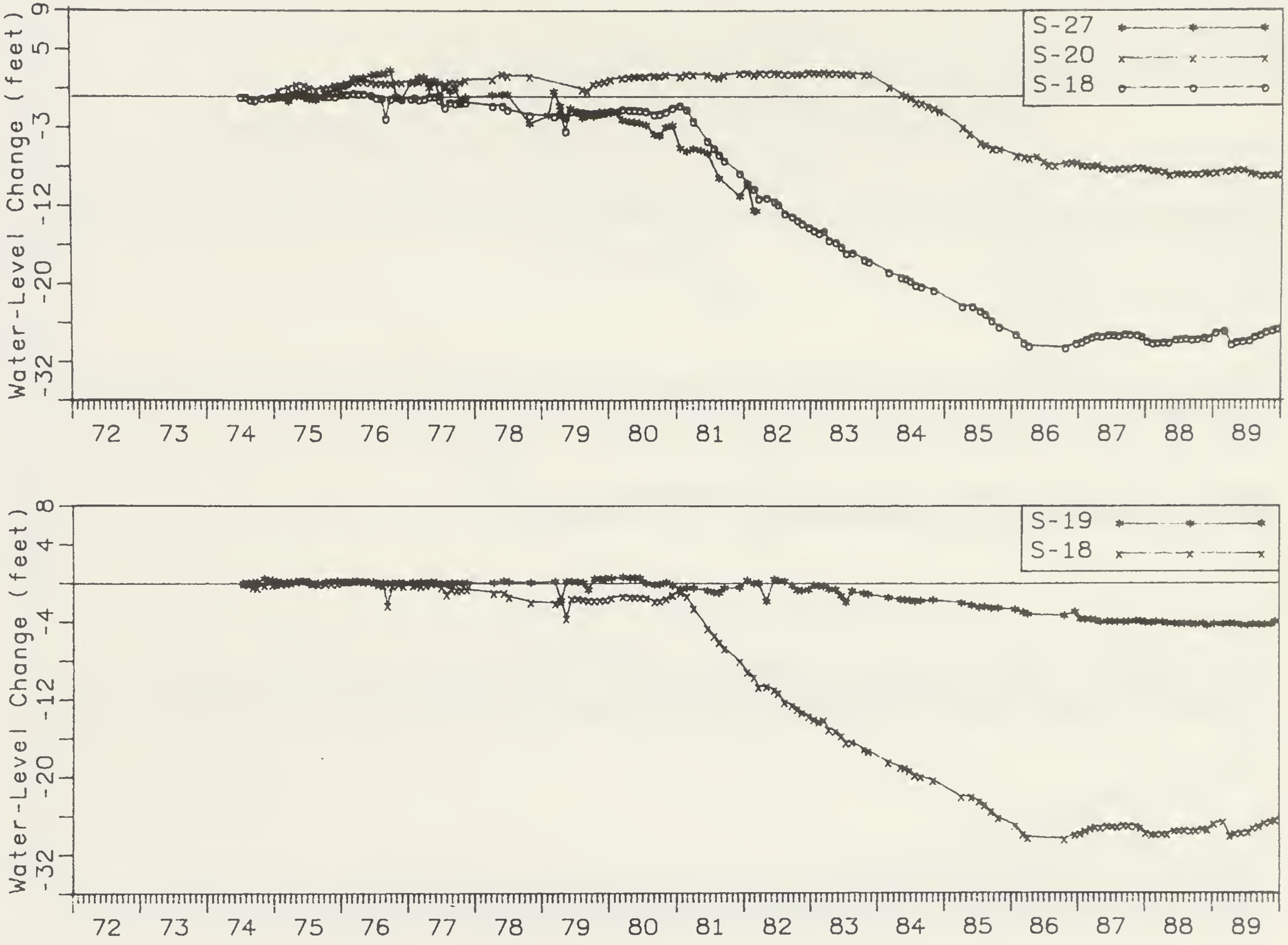
Hydrographs

On the following pages, hydrographs of selected monitoring wells show water-level changes associated with non-disturbed, disturbed, and post-disturbance conditions. The first 5 sheets describe water levels at and near the Rosebud and Big Sky mines. Following sheets address changes near the East Decker, West Decker, and Ash Creek (Wyo.) mines. In all areas important reactions to mining are being recorded, particularly:

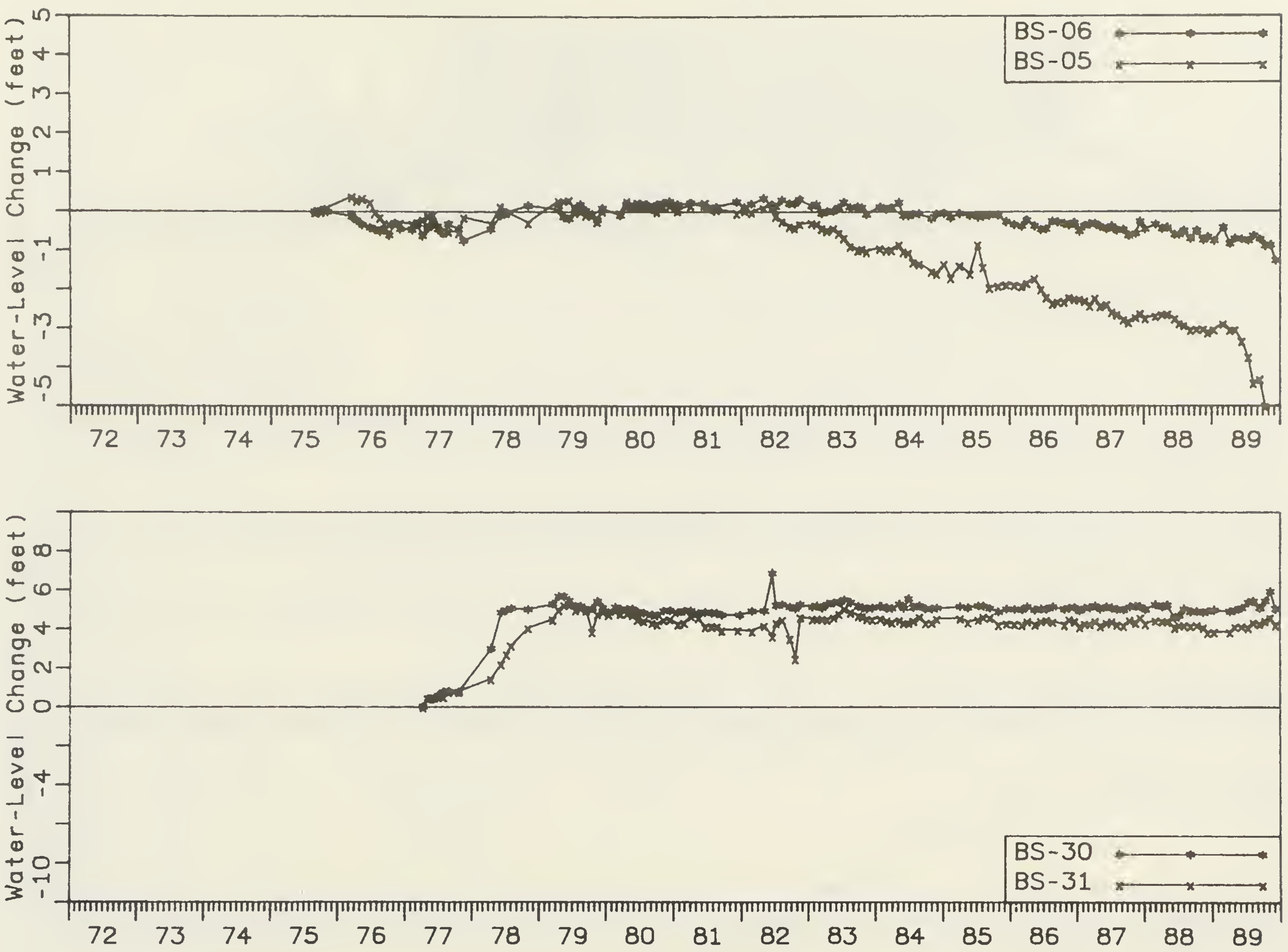
1. Water levels in aquifers lying below the disturbed depths are declining, probably because of coal exploration holes that act as conduits to vertical ground-water flow.
2. Water levels in alluvium adjacent to, and overlying hydrostatic depressions are not reacting to mining. The one known exception is local along E. Fork Arwells Creek where mine pits have penetrated the alluvial aquifer.
3. Resaturation of mine spoils is more or less complete within about 3 years after the back-filling of pits.



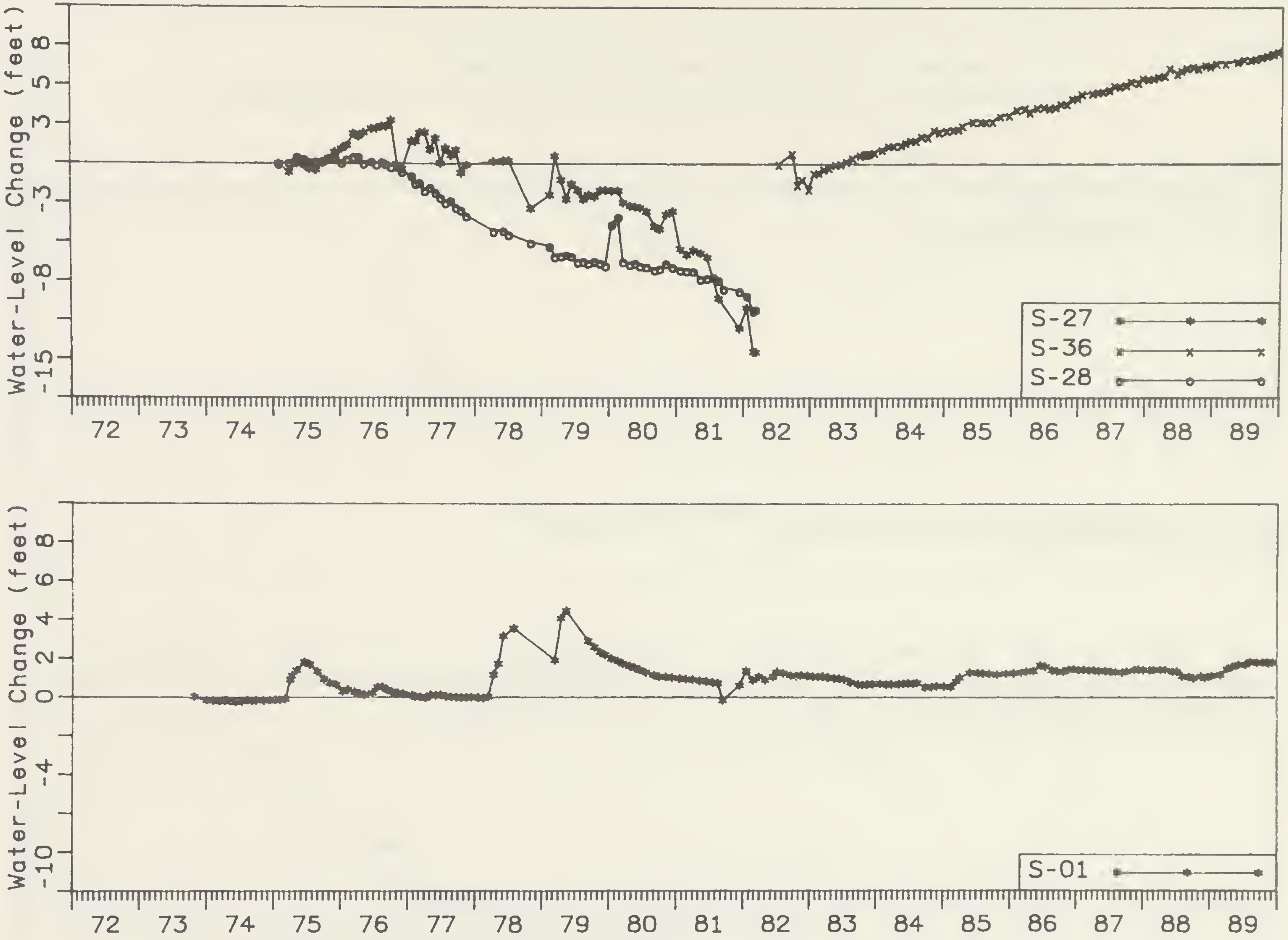
HYDROGRAPH 1 Along East Fork Armells Creek, the water table upstream (P-08) and downstream (P-11) from mining activities has not been affected; near the mines (P-05), the water table has dropped about 3 feet. The water table near the Big Sky mine (BS-14) has not significantly changed.



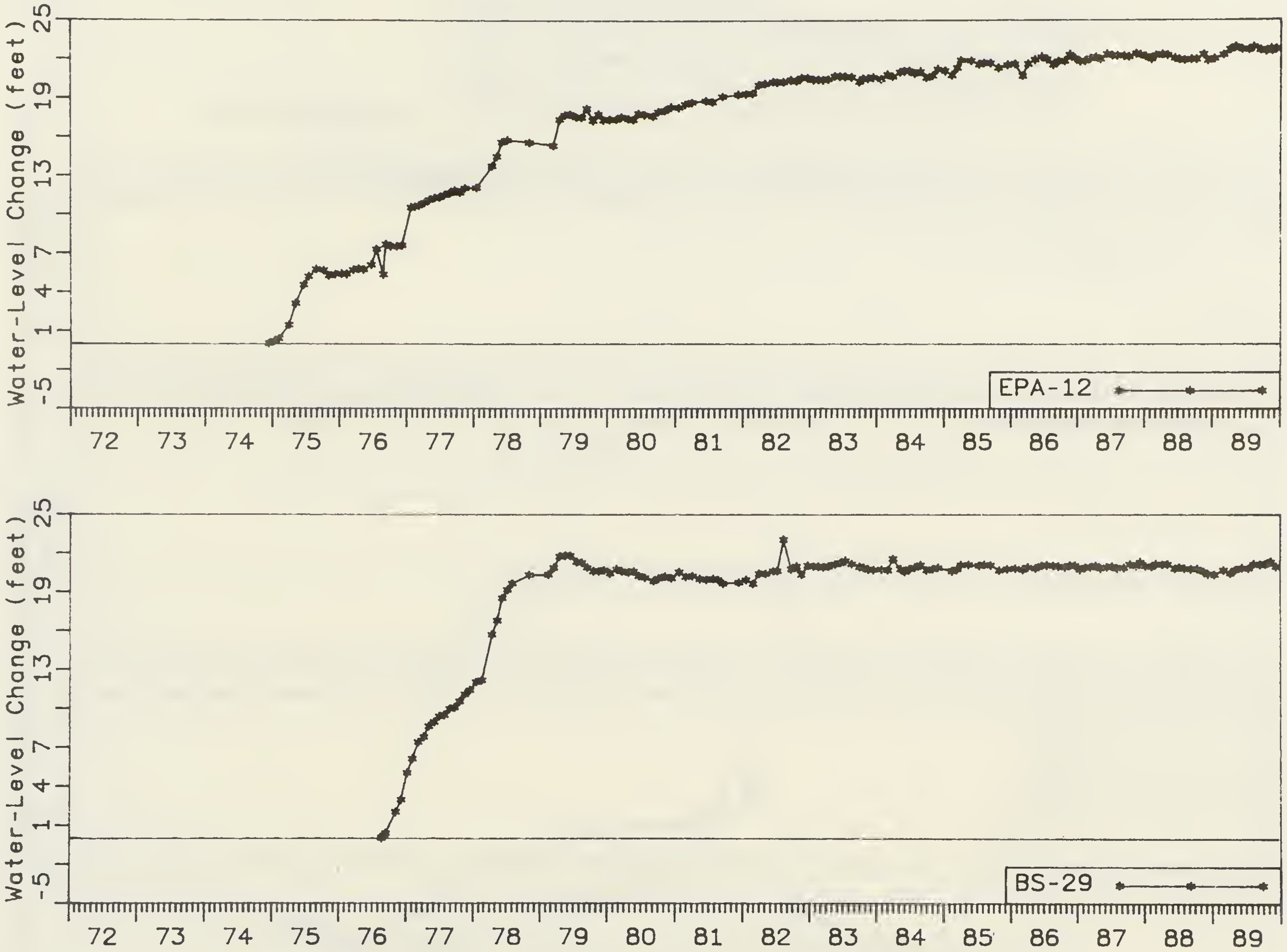
HYDROGRAPH 2 Water levels for the McKay coal bed near the Rosebud mine have declined strongly as a result of mining (S-27, S-20, and S-18), even though the McKay coal bed is not being mined. Water levels for the Rosebud coal bed being mined at the same location (S-19), have declined in lesser amounts.



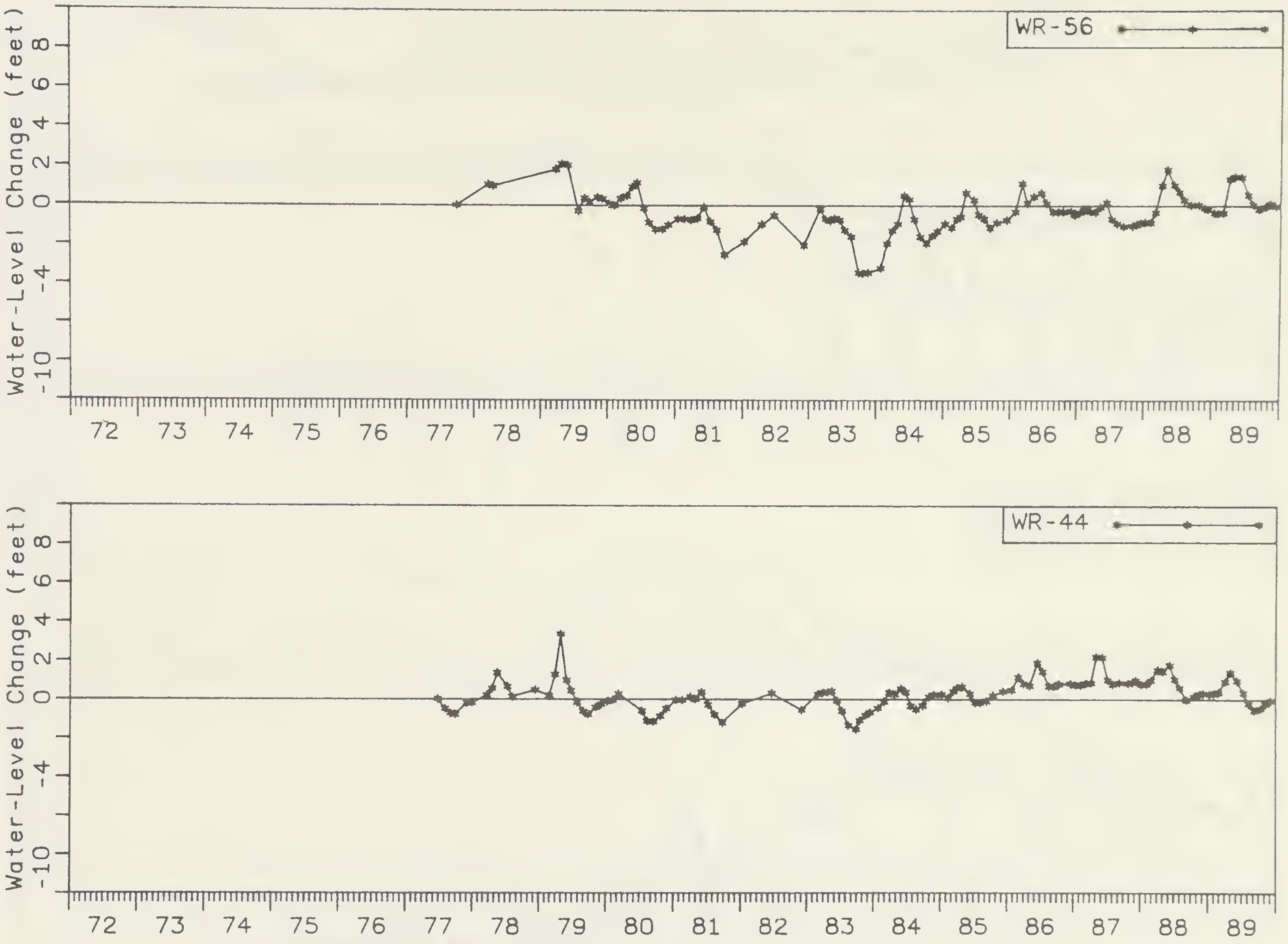
HYDROGRAPH 3 At the Big Sky mine, the Rosebud and McKay beds are being mined, and water levels for both beds are declining; effects on the McKay coal bed (BS-05) are greater. Where the mine pits have been backfilled, nearby water levels in the Rosebud coal bed (BS-30, BS-31) have recovered, perhaps to pre-mining levels.



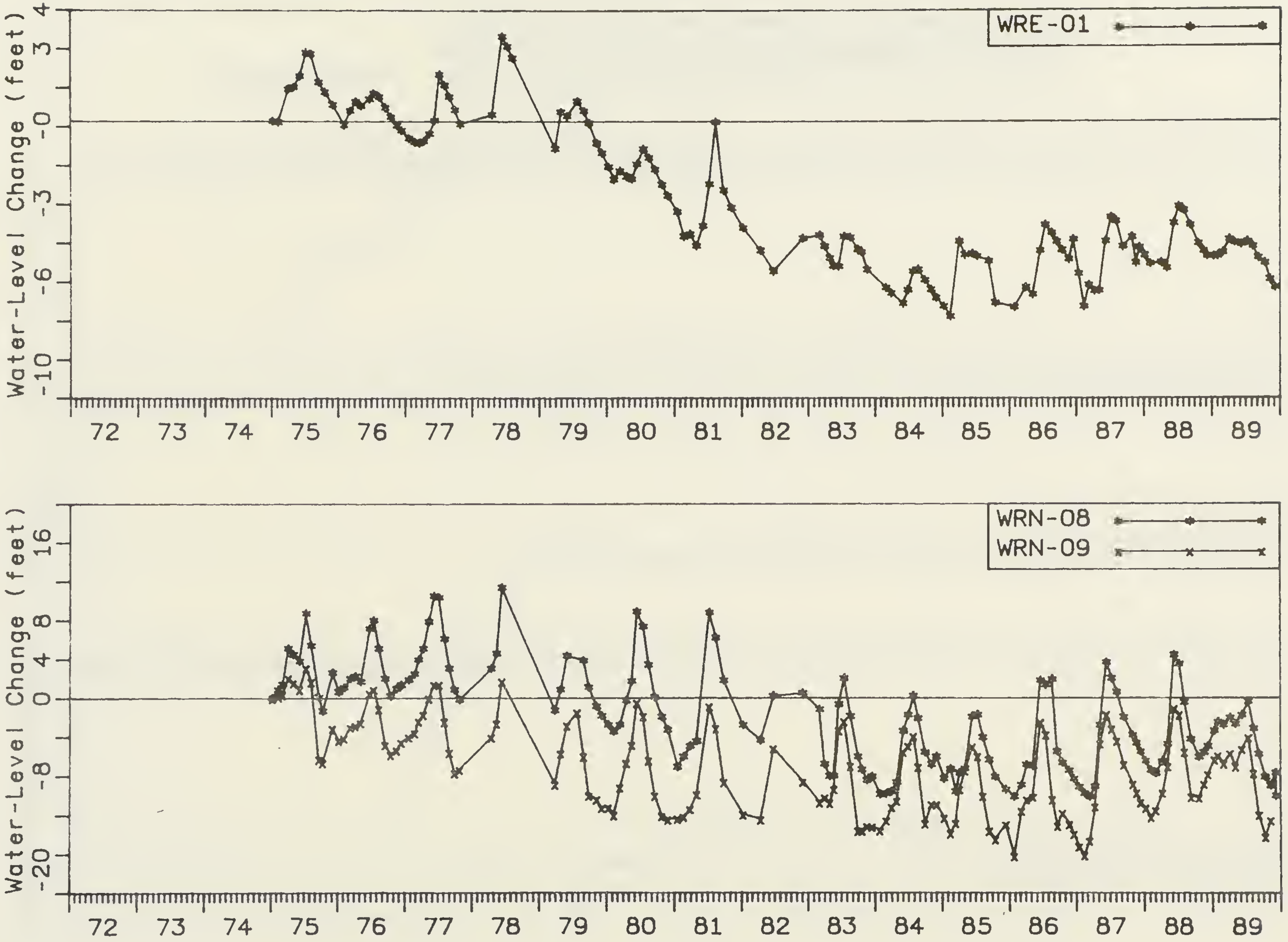
HYDROGRAPH 4 Coal-aquifer water levels in wells near the Rosebud mine declined steadily until wells were mined (S-27, S-28). After backfilling at that location, water levels in spoils began a steady recovery (S-36). Water levels in older spoils (S-01) have reached equilibrium, and respond to recharge only during optimum years.



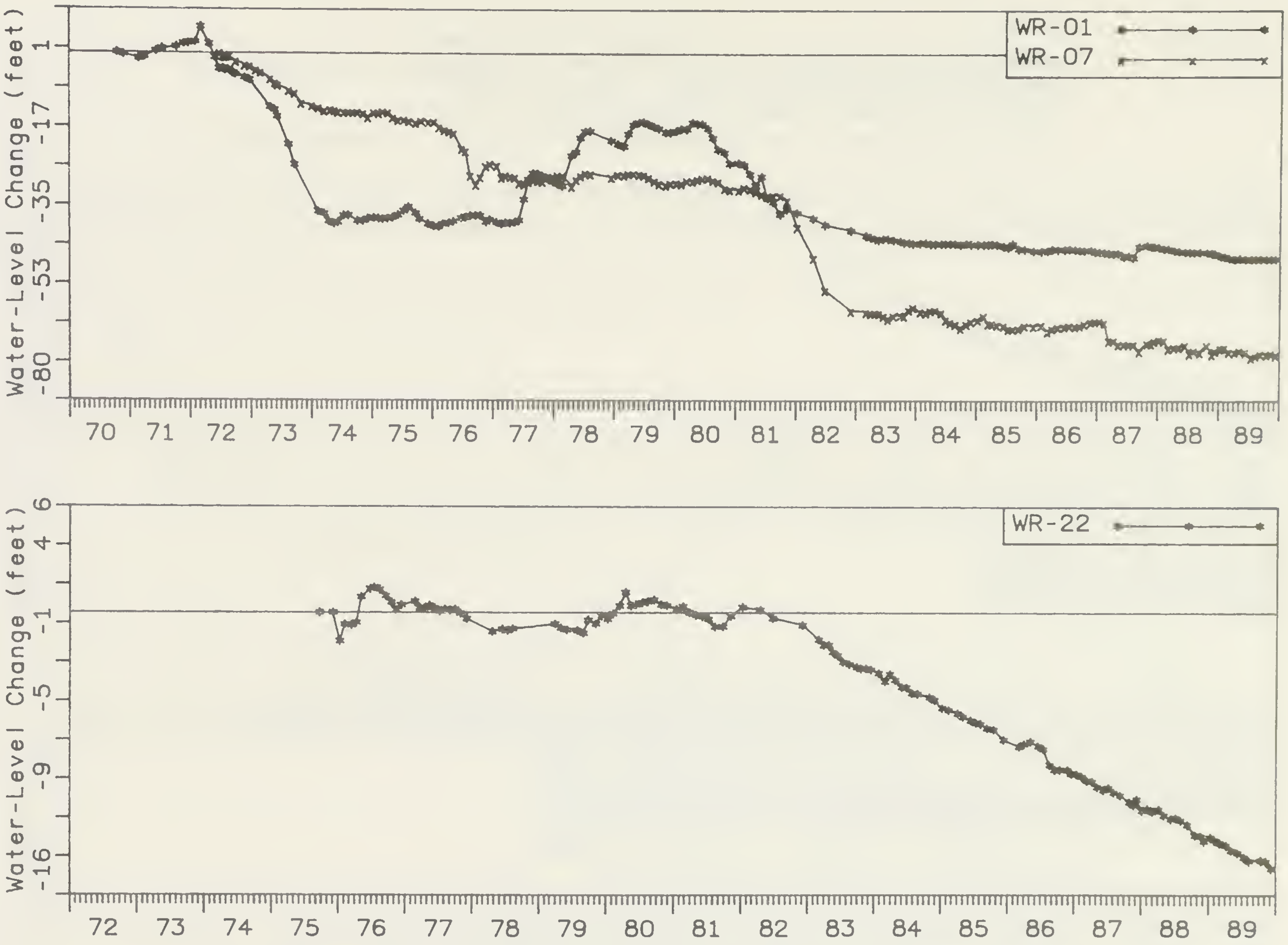
HYDROGRAPH 5 Mine-spoils water levels have risen rapidly after backfilling at the Rosebud mine (EPA-12) and at the Big Sky mine (BS-29).



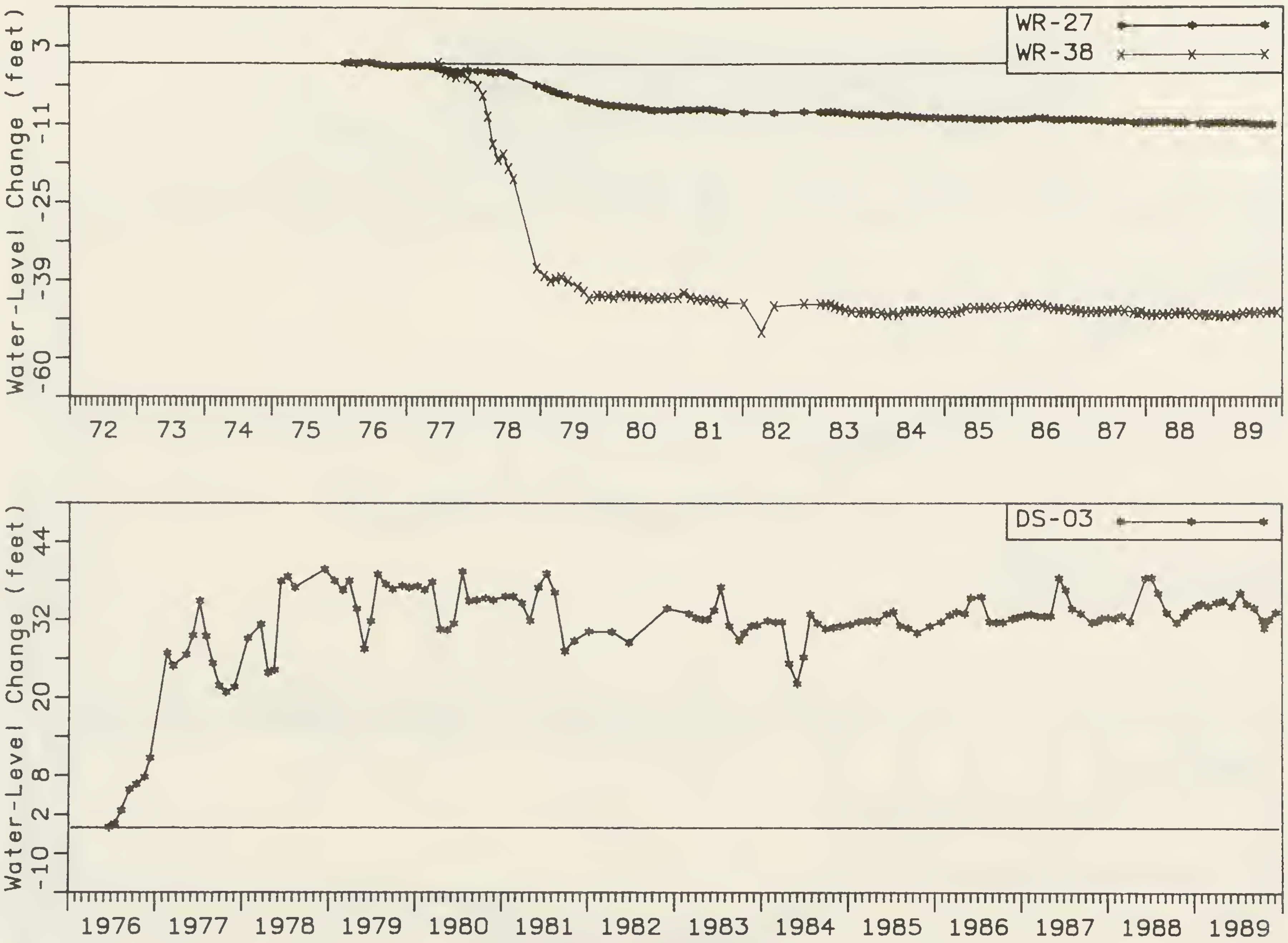
HYDROGRAPH 6 Near Decker, water levels in alluvium along Squirrel Creek (WR-56) and along Youngs Creek (WR-44) have not declined despite extensive drawdowns for coal-bed aquifers below the valley floors.



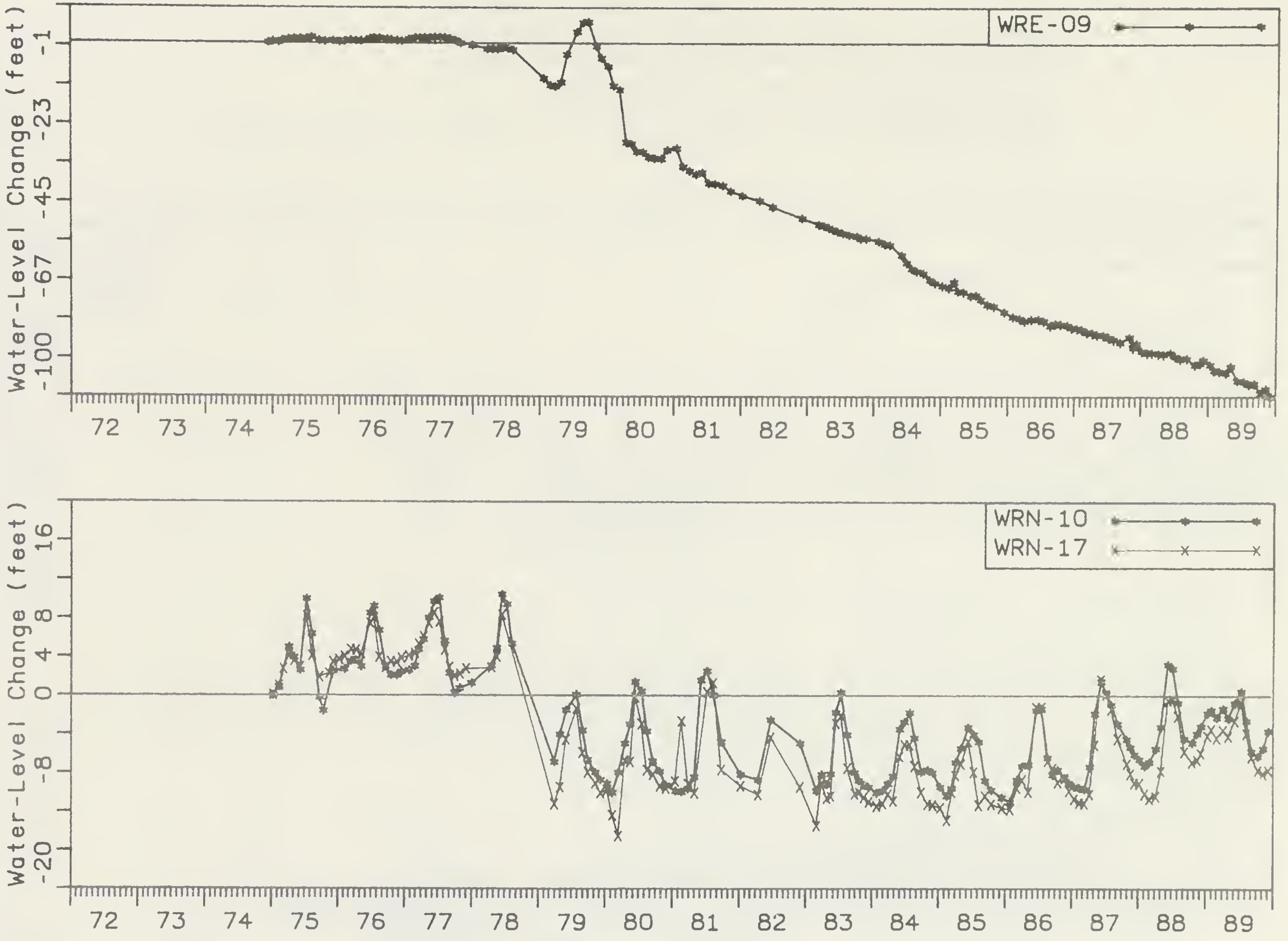
HYDROGRAPH 7 Stage levels for Tongue River Reservoir control water levels in adjacent alluvium (WRE-01) and in nearby coal-bed aquifers (WRN-08, WRN-09).



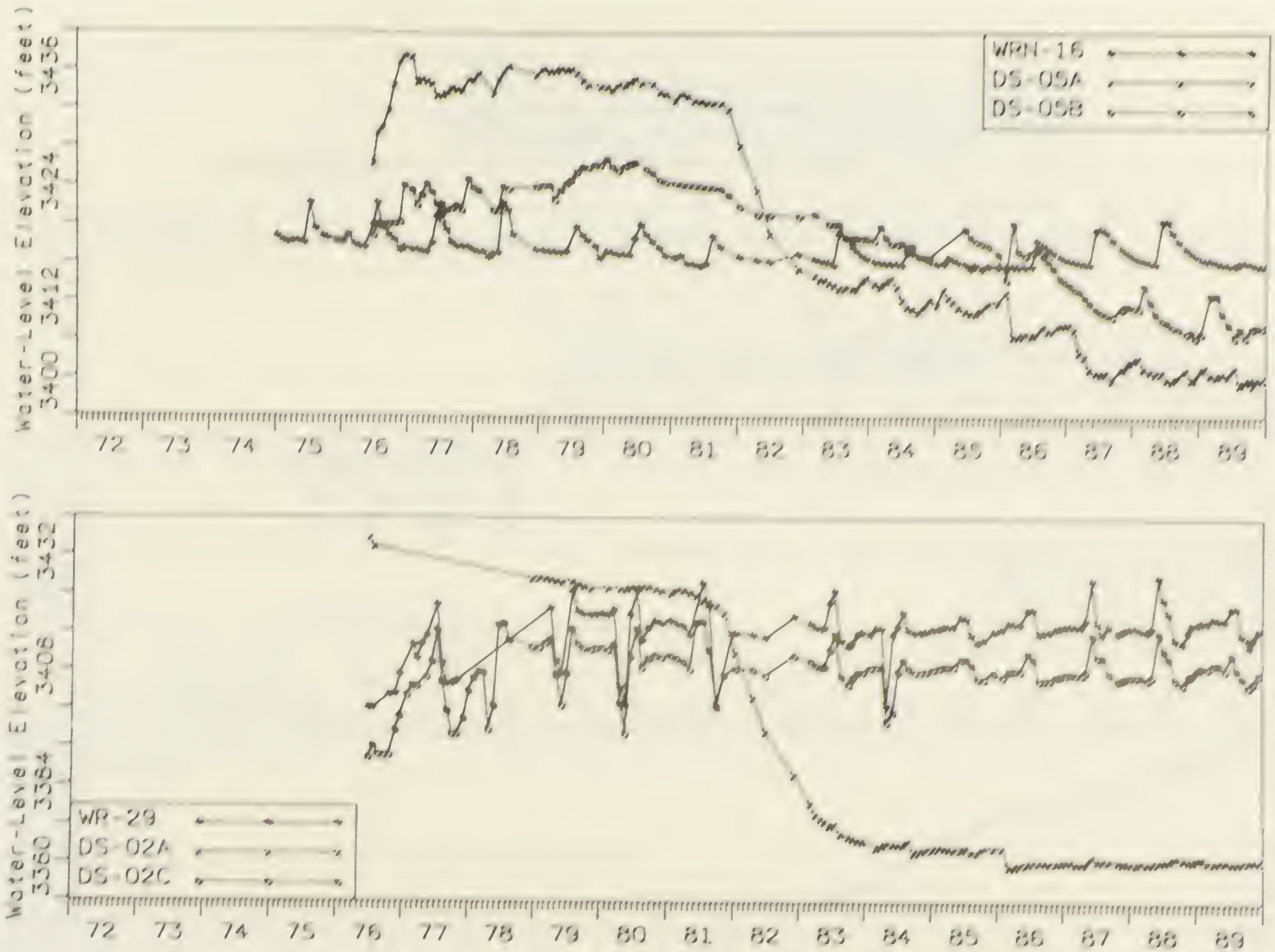
HYDROGRAPH 8 At the West Decker mine, water levels for the D-1 coal bed (WR-01) and the D-2 coal bed (WR-07) declined rapidly when mining of the former began. Mining of the D-2 coal bed, beginning in 1981, caused increased drawdowns. Drawdown continues 3-1/2 miles west of the mine at WR-22.



HYDROGRAPH 9 Water levels in coal aquifers near the Ash Creek mine in Wyoming declined rapidly, followed by a leveling in response to a constant-head boundary (WR-27, WR-38). Following backfilling at the West Decker mine, water levels in the newly created spoils aquifer rose 40 feet within 2 years (DS-03).



HYDROGRAPH 10 Near the East Decker mine, water levels for the D-2 coal bed (WRE-09) began a sharp decline when the mine opened in 1978. Drawdowns passing westward beneath the Tongue River Reservoir may be the sharp declines for the D-2 coal bed at WRN-10 and WRN-17.



HYDROGRAPH 11 Water levels for the D-2 coal bed (DS-05A), mine spoils (DS-05B), and off-site water table (WRN-16) demonstrate vertical flow between the D-2 coal bed and spoils at the northern end of the West Decker mine. At the south end, there is lateral flow from the off-site water table (WR-29) to the spoils (DS-02C), with little or no influence from the deeper D-2 aquifer (DS-02A).

4. The resaturation occurs laterally by flow from adjacent undisturbed aquifers and vertically by flow from deeper aquifers, probably through coal exploration holes.

Additional data and more detail can be found in Montana Bureau of Mines and Geology Memoir No. 62, published in 1988.

WATER QUALITY EVOLUTION

Commonly considered the "major chemical" constituents in water are the cations calcium (Ca), magnesium (Mg), and sodium (Na), and anions sulfate (SO_4), bicarbonate (HCO_3), and chloride (Cl). Concentrations and relative abundances of these ions in ground water reflect geochemical processes that are active in ground-water flow systems (Figure 2). The relative abundance of any cation or anion is expressed by its concentration (milliequivalents per liter) as a percentage of the total concentration of cations or anions. Other ions identified on Figure 2, carbonate (CO_3) and potassium (K), are also common, but usually in relatively very low concentrations. In the coal-bearing and associated sediments of southeastern Montana, the major constituent, chloride, also occurs in very low concentrations, probably because of the non-marine origin of the sediments. The remaining 5 comprise 97-or-more percent of the dissolved contents in almost all ground water in Fort Union and other shallow aquifers.

Recharge areas are characterized by oxidizing conditions. Oxidation enhanced by mechanical weathering of geologic materials generates large amounts of salts that are readily available for dissolution by percolating ground waters. Percent ion concentrations for ground water in recharge areas would plot in either the left-hand or the lower quadrilateral of Figure 2, depending upon available soluble salts. Where products of sulfide weathering (sulfates) are present, the plots would be toward the left, and dissolved-solids contents would be the largest. In the absence of sulfates, plots would be toward the bottom and dissolved-solids contents would be much smaller.

As ground water moves away from sources of soluble salts, cation-exchange processes modify the relative proportions of dissolved ions. Sodic clays, abundant in the Fort Union Formation, selectively adsorb the divalent calcium and magnesium ions onto their surfaces and release monovalent sodium ions to the water through ion exchange mechanisms grouped as "natural softening" reactions. Sodium then becomes the strongly predominant cation, and the dissolved-solids concentrations remain high.

Simultaneously with cation exchange, sulfate-reduction reactions decrease the proportion of sulfate relative to bicarbonate. Dockins and others (1980) found significant numbers of sulfate-reducing bacteria in 25 of 26 water samples collected from aquifers in southeastern Montana. These anaerobic bacteria obtain their energy by oxidizing certain simple organic compounds, and also produce sulfide from reduction of sulfate by the following reaction:

$$2\ CH_2O + SO_4^{-2} = H_2O + CO_2 + HCO_3^{-} + HS^{-}.$$

Carbon dioxide and hydrogen sulfide gases in waters in many aquifers of the area are products of this reaction.

The combined effect of the exchange and reduction processes is a modification of ground-water quality so that sodium and bicarbonate are ultimately the predominant constituents, and the dissolved-solids concentrations are less than about 2000 mg/L. Where exchange and reduction processes are highly active, such as the Decker area, the

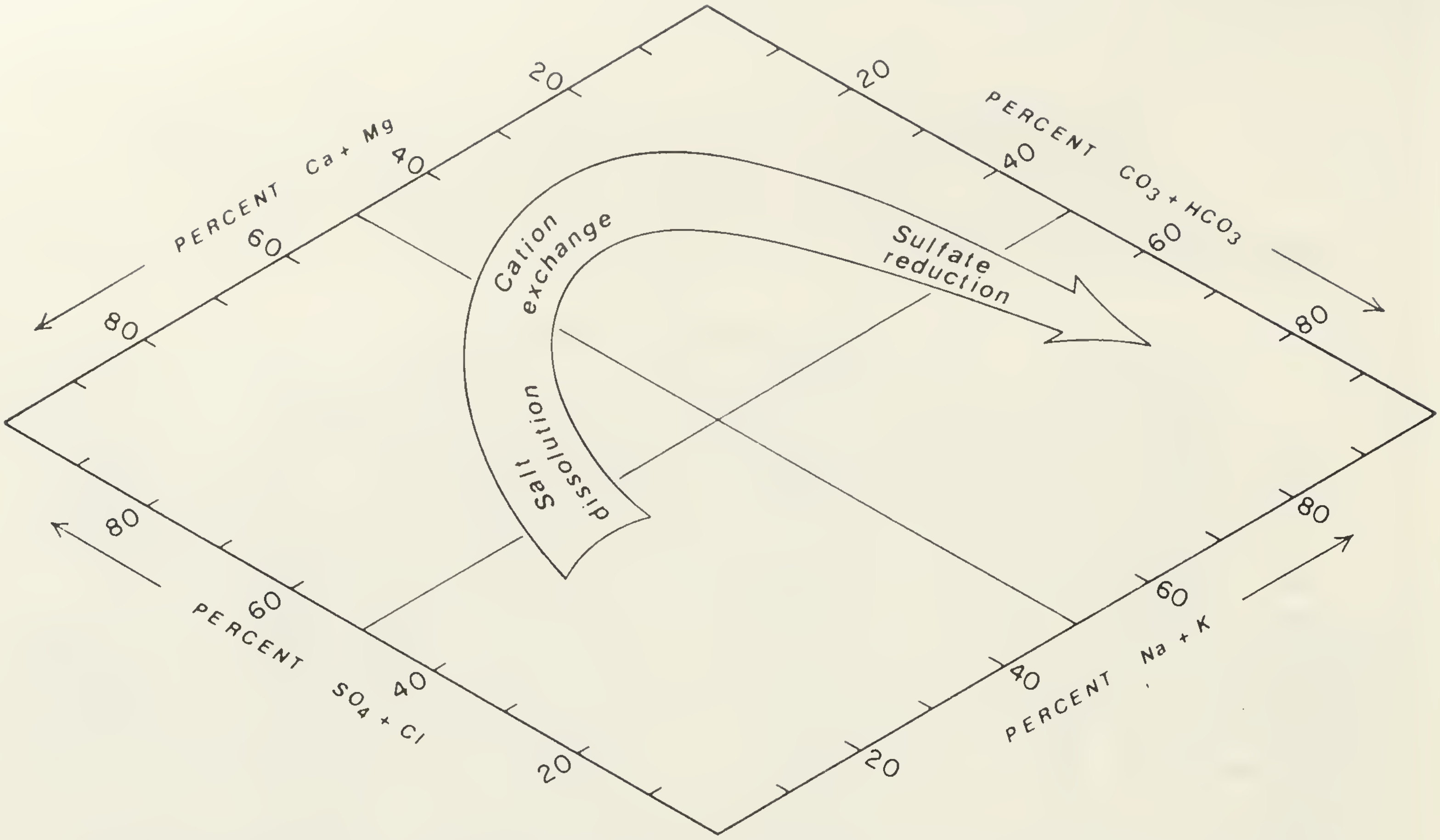


Figure 2—Chemical characteristics of ground water are altered by natural processes along the path of flow.

sodium-bicarbonate character of water evolves within a very short distance downgradient from the recharge sites. Thereafter, the water quality remains relatively uniform. The reduction process does not seem active in the Colstrip area, so the quality of most ground water there is a product of salt dissolution and, to a lesser degree, cation exchange.

Water-Quality Changes

Figures 3 through 7 demonstrate water-quality changes at selected monitoring wells at eastern Montana surface coal mines. The information is given in terms of dissolved-solids contents and percentage concentrations of sulfate and of calcium plus magnesium. Referring back to Figure 2, increases in percentages of sulfate and calcium plus magnesium indicate dissolution of salts, primarily weathering products. Decreases in those percentages along with decreased dissolved-solids contents result from the flushing of salts from the system and/or the processes of cation exchange and sulfate reduction. Water-quality data for these and many additional monitoring wells can be found in Montana Bureau of Mines and Geology Memoir No. 62.

SUMMARY

Mining of subbituminous coal in southeastern Montana has accelerated since 1968 to a current annual production exceeding 30 million tons. Climate of the area is semiarid, so agricultural enterprises there are reliant upon wells and springs for stock and household water supplies. Many of the coal beds destined for mining are also aquifers that supply vital ground water.

Ground-water levels near mines along aquifer outcrops, such as near Colstrip, do not change substantially during mining. In contrast, mines that have penetrated a more-central part of a flow system near Decker

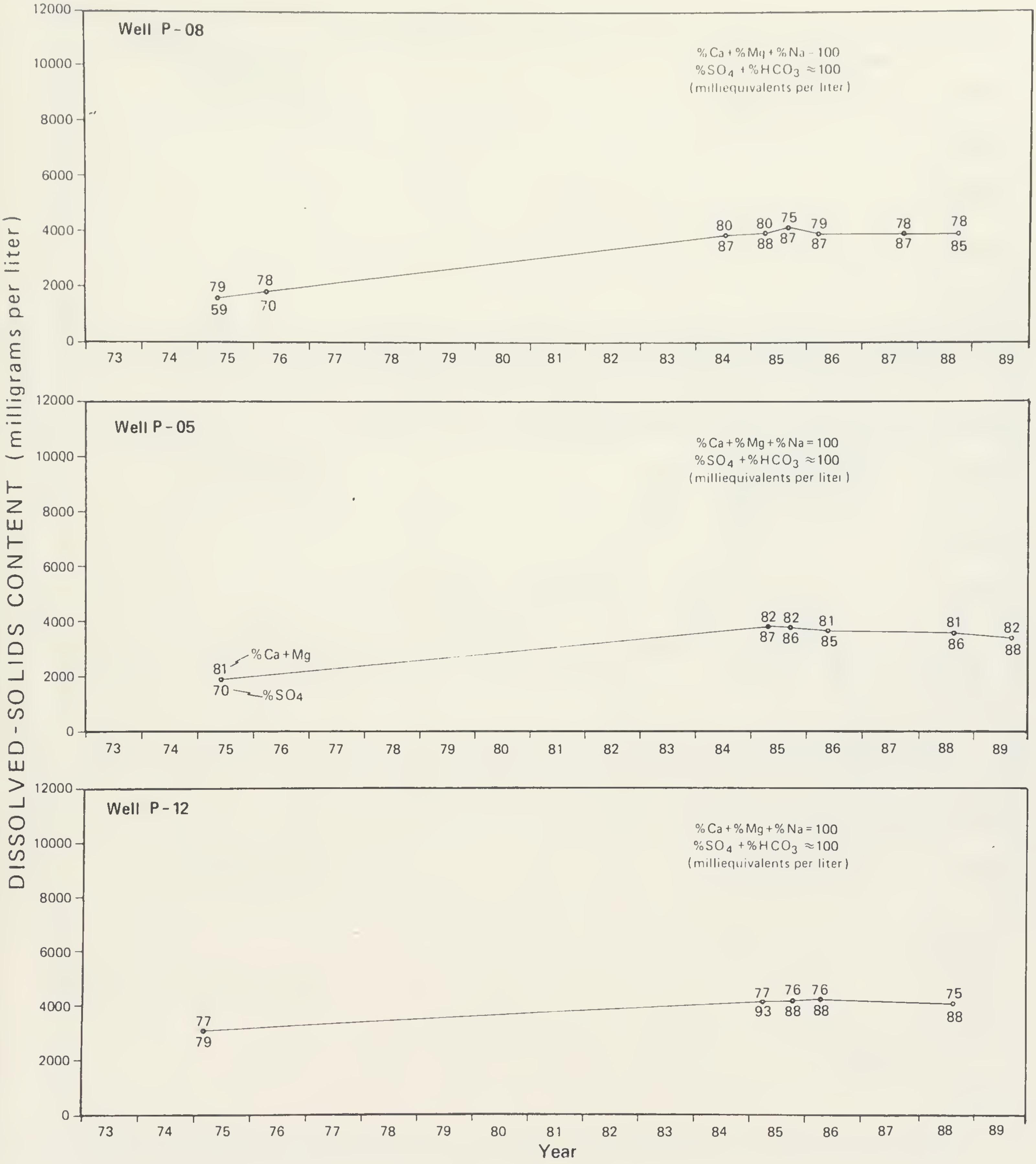


Figure 3 – Dissolved-solids contents and sulfate percentages have increased in shallow ground water along East Fork Armells Creek upstream from mining (well P-08), near mining (well P-05), and downstream from mining (well P-12).

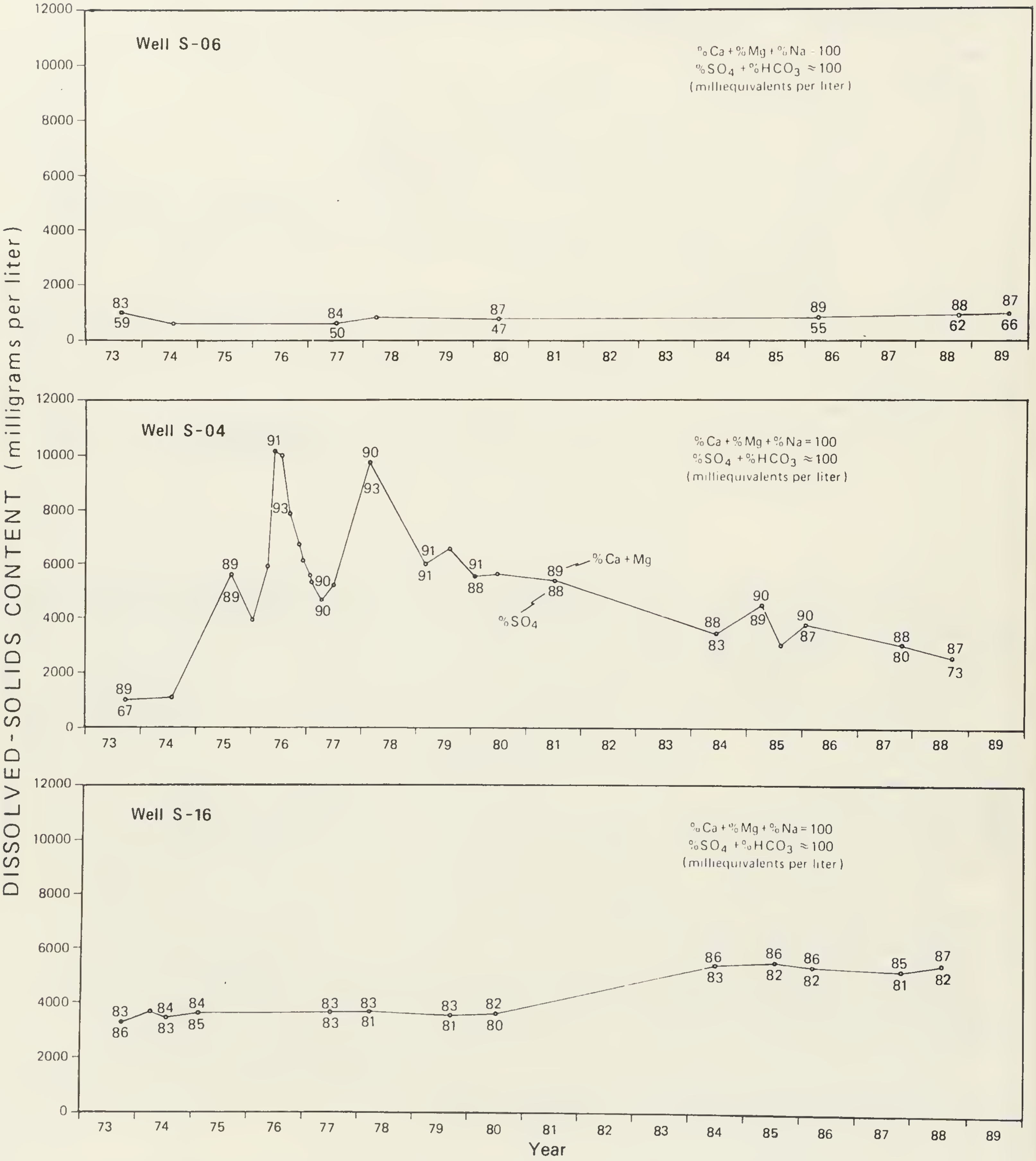


Figure 4—Off-site water quality in most places (well S-06) has been uniform since 1973. Local exceptions (S-04, S-16) may be mining related.

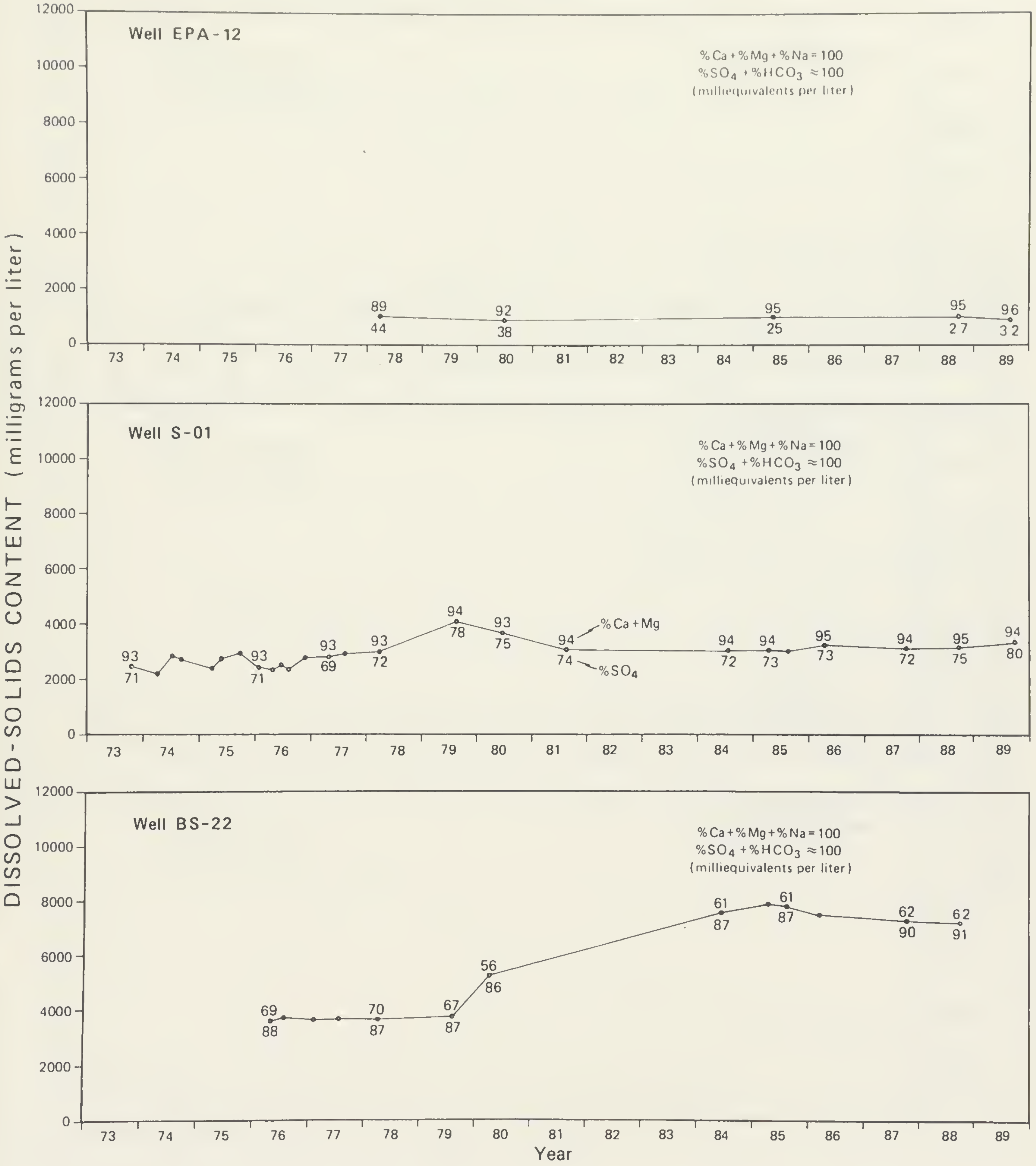


Figure 5 — Soluble salts have been flushed from the spoils aquifer at well EPA-12; at well S-01 they are increasing, and at well BS-22 a local plume of highly mineralized spoils water has developed.

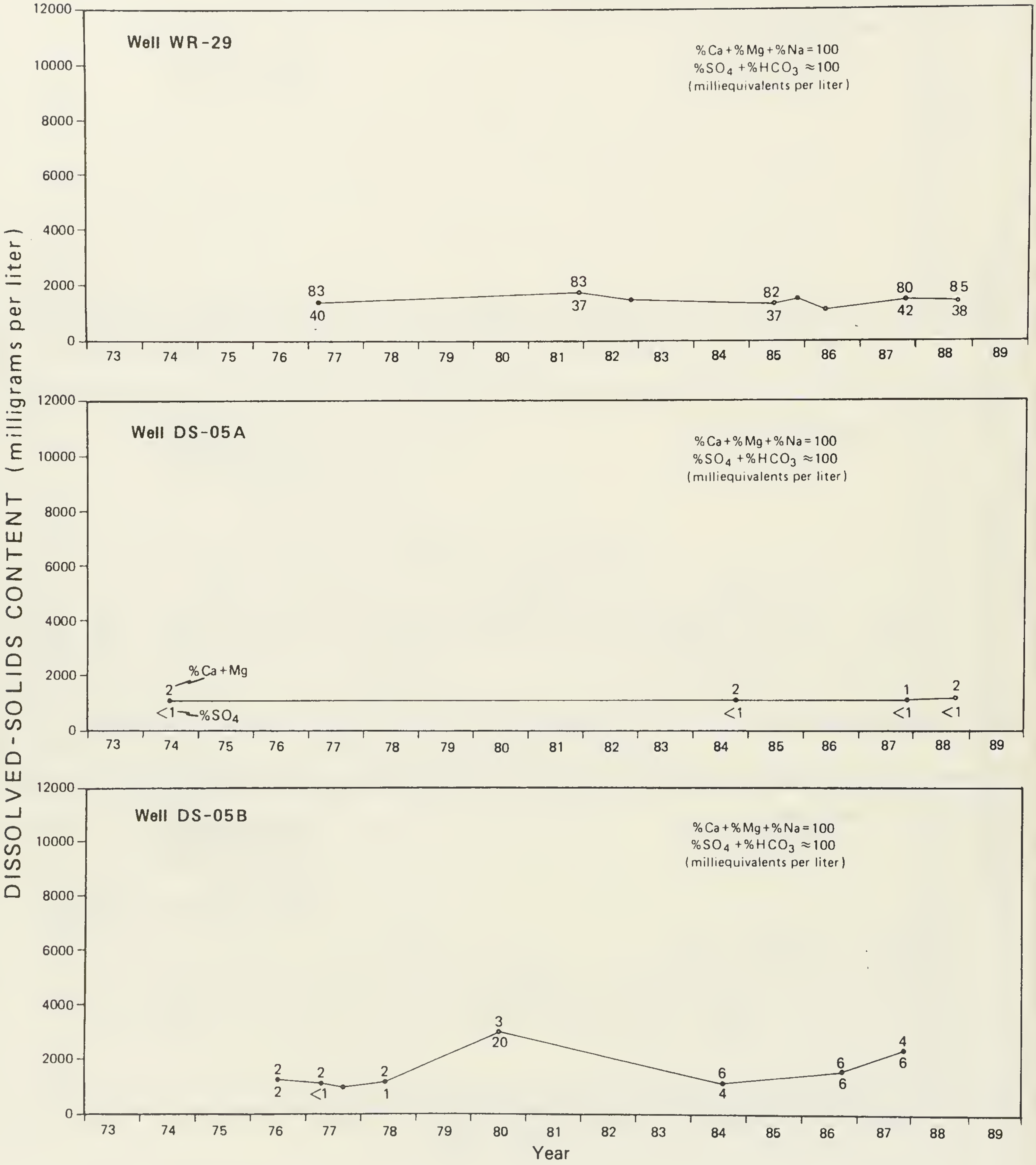


Figure 6 —Water quality in Tongue River alluvium (well WR-29) and in the D-2 coal bed at the West Decker mine (well DS-05A) has been uniform. Quality of spoils water at well DS-05B has been erratic.

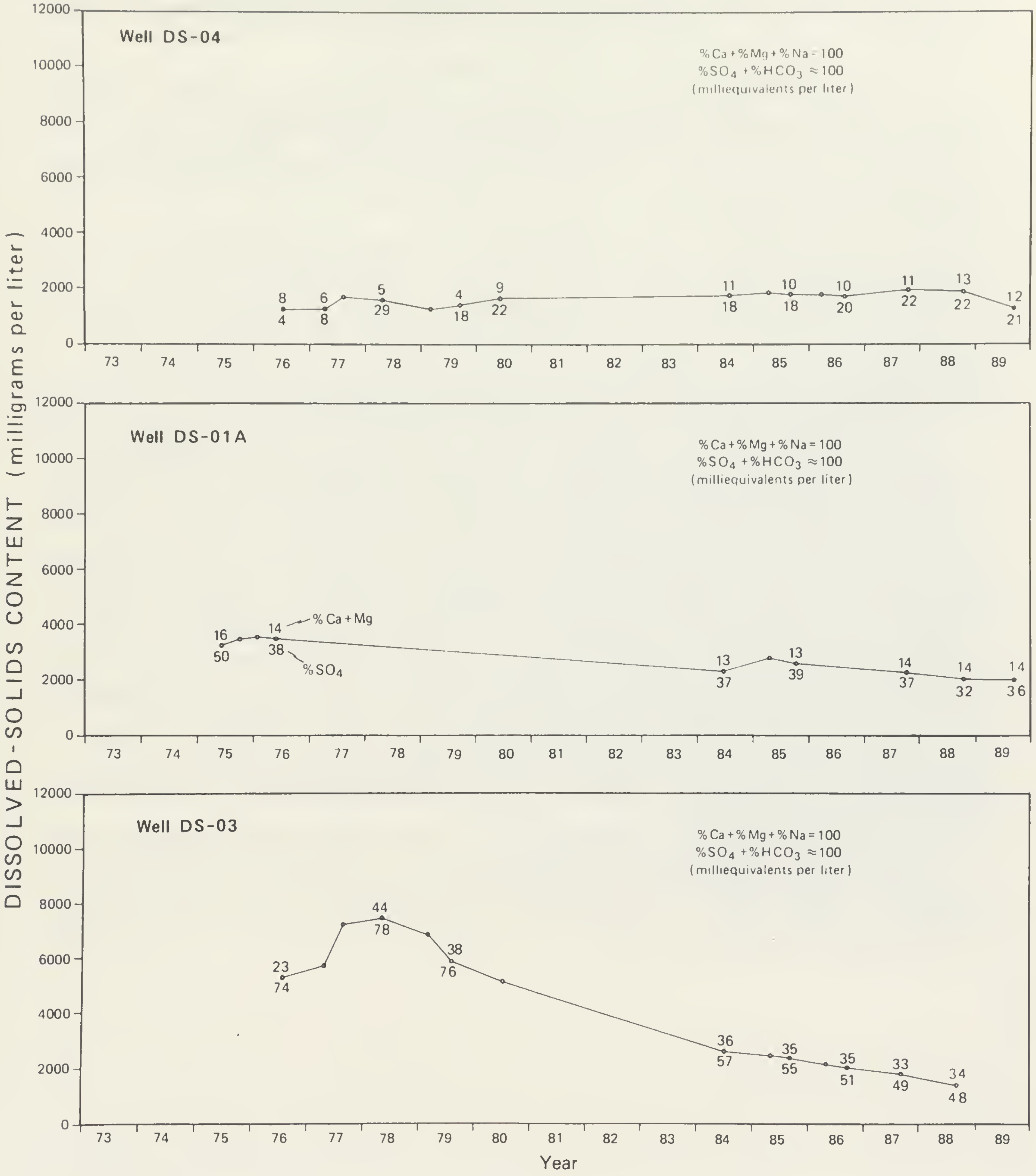


Figure 7 – Increases in dissolved solids are occurring in spoils water at well DS-04; trends of decrease are evident in other spoils water.

thus far have caused potentiometric declines over an area more than 15 miles long and 5 miles wide. Although the large area of drawdown passes beneath valleys containing perennial streams and alluvial aquifers, alluvial water-table changes have not occurred. Confining beds of clay above the coal-bed aquifers effectively isolate the decreased hydrostatic pressures from shallower ground water.

As backfilling follows coal removal, ground water re-enters spoils at the mines. Greatest resaturation thus far has occurred through recharge by lateral flow from undisturbed aquifers. Where vertical gradients are favorable, upward flow (possibly through pre-mining test holes) can be significant. Whether by test holes or other means, hydraulic connection between the mines and deeper aquifers is documented by hydrostatic-pressure changes that occur during mining. Substantial ground-water flow in spoils occurs along "mine-floor" aquifers where a variable thickness of wasted coal and coarse rubble have been covered by finer-grained materials. Evidence is very strong that the spoils do not act as barriers to ground water flow and, in some places, can provide adequate quantities of water for stock or domestic use.

Water quality in new mine spoils is highly diverse because of the variable distributions of soluble salts after backfilling. With resaturation and the establishment of new flow patterns, water quality seems to become dependent on a balance between introduction of new salts through recharge and the flushing of salts by ground-water flow. At some wells at the Rosebud mine, recharge from the surface is introducing new salts as fast or faster than they can be flushed. Near a surface basin there, very active recharge and ground-water flow appear to have flushed most available salts from the locale already. At some wells in Decker spoils, trends toward decreasing concentrations of dissolved solids are being established. Here, recharge from adjacent undisturbed aquifers is beginning to flush salts from the mine-floor aquifers.

If trends for progressively decreasing dissolved-solids contents should become apparent at several more monitoring sites, better projections of the time needed to approach pre-mining water-quality conditions can be made.

The area of hydrostatic-pressure declines near Decker continues to broaden, providing important new information on cumulative mining impacts. Information important for predictions of post-mining water-quality trends seems to be developing as well, and should be reassessed as new data become available.

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

THE MANAGEMENT OF MINEWATER SALINITY IN BALLARAT

C.S. Joy[1]

ABSTRACT

Ballarat Goldfields Limited is currently re-opening the old workings of the East Ballarat Goldfield which contain an estimated 1800 ML of groundwater. The disposal of this 'minewater' was of concern: the minewater is of moderate salinity; increased salinity levels have interfered with agriculture and water use at a number of locations downstream from Ballarat. Extensive numerical studies indicated that treated minewater could be discharged into the Ballarat Creek system for dilution by sewage effluent and by surface runoff after rainfall events. An automatic real-time salinity management system has been developed to enable the disposal of saline minewater in this fashion. A desk top computer operates the system: discharge and salinity readings are taken automatically each hour and filed away; the maximum allowable rate of discharge of treated minewater is calculated; pumps are switched on and off. The system readily enables daily, weekly and monthly data reports together with floppy disks of 'raw' data to be prepared in formats suitable for direct submission to the Victorian Environmental Protection Authority.

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INTRODUCTION

Ballarat, a city of 70,000 people, is located in the central region of the State of Victoria, Australia after the discovery of gold in 1851, mining progressed through three phases: shallow alluvial (1851-52), deep alluvial (1853-75), and hard rock quartz (1854-1918). In all, some 560 tonnes of gold was won from the Ballarat Goldfields between 1851 and 1918, an amount greater than the combined total of the Californian and Alaskan Goldfields.

Deep mining ceased in Ballarat in 1918 through a combination of circumstances. Ore grades were declining; miners enlisting for service in the First World War caused a manpower shortage; groundwater problems were increasing.

Groundwater inflows to underground workings were always a potential problem in Ballarat. Difficulties were compounded by the inefficiencies of early pumping equipment. When mining ceased, there were over 400 km of underground drives beneath Ballarat, many of which were interconnected. Thus, as mines progressively closed down, a dwindling number of operating mines had to remove an ever increasing amount of groundwater. Today, most of the underground workings are filled with groundwater that is characterized by moderate salinity and high levels of iron, arsenic and manganese.

Ballarat Goldfields Limited, an Australian Company formed in 1984, is currently re-opening the old workings of the Ballarat East Goldfield. Figure 1 shows the location of the mining lease, which encompasses a heavily urbanised area of Ballarat. The development of a major goldmine in the midst of an urban area is somewhat remarkable. Careful mine planning, together with a detailed assessment of the social and environmental consequences, were necessary to ensure that the new mine would be socially, environmentally and financially successful.

PROPOSED MINE WORKINGS

Figure 1 shows the location of the proposed mine workings. These are divided between sites 'A' and 'B', which are some 1.2 km apart. Initially, dewatering of the old workings and treatment of the 'minewater' will take place at Site 'A', Llanberris Reserve. The Llanberris No. 1 shaft has been re-opened for dewatering purposes. Over 2.7 tonnes of gold was won from this mine in the past. An access shaft, ore crushing and treatment facilities, a tailings disposal dam and a groundwater storage dam are currently being constructed at Site 'B', the Larter Street site. A vertical boring machine is being used to drill a shaft 4.2 m in diameter at Site 'B'. This shaft will connect to the old East Ballarat workings via a ramp. Dewatering and water treatment facilities identical to those at Site 'A' will also be constructed at Site 'B'.

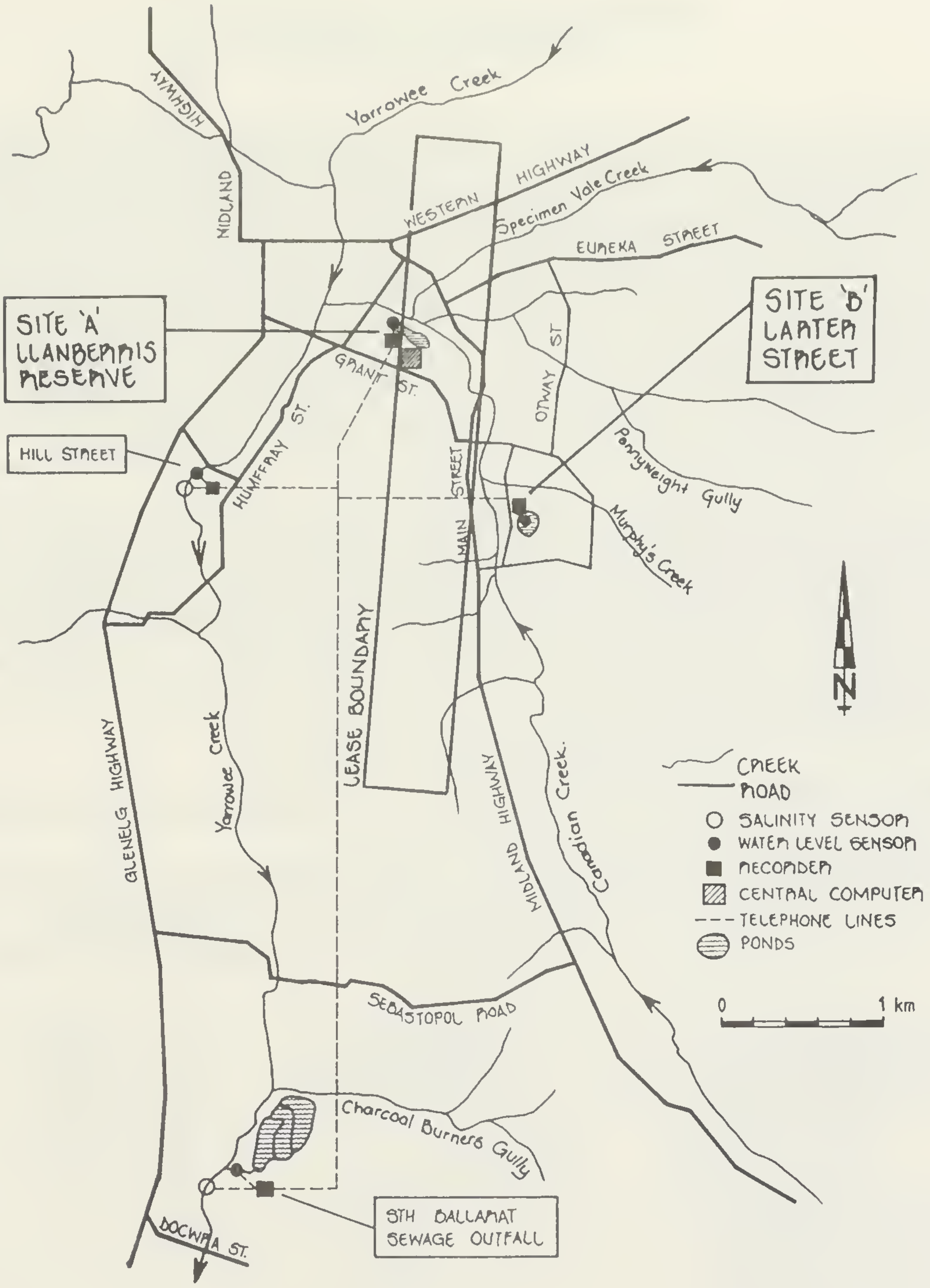

Figure 1 Locality Map, Ballarat

THE URBAN DRAINAGE NETWORK

Figure 1 shows the Ballarat Creek system around Sites 'A' and 'B'. Canadian Creek, a northerly flowing waterway passes in close proximity to both Sites 'A' and 'B' before joining Yarrowee Creek, a southerly flowing waterway that is the main drainage channel of the Ballarat urban area. The South Ballarat Sewage Treatment Plant (STP) discharges tertiary treated sewage effluent into Yarrowee Creek at a location some 5.5 km downstream from the confluence of Canadian and Yarrowee Creeks (see Figure 1).

MINEWATER QUANTITY AND QUALITY

On the basis of mine plans of the original workings, the underground workings of the East Ballarat Goldfields were estimated to contain some 1800 ML of minewater. Dewatering operations will take place over a 12-18 month period and involve pumping rates of up to 6 ML/d. Pumping figures in old mine reports were used to estimate the rate of groundwater inflow at the closure of the field. This figure, together with a regional assessment of groundwater behaviour, indicated that maintenance pumping at up to 2.5 ML/d would be necessary to maintain water levels once the old workings were emptied.

The minewater contains elevated levels of iron, arsenic and manganese and is of moderate salinity (filterable residue). Table 1 shows typical water quality results together with allowable discharge levels, as stipulated by the Victorian Environmental Protection Authority (EPA). It is apparent that iron, arsenic, manganese and salinity levels need to be reduced before groundwater can be discharged into the Ballarat creek system.

Table 1 Water Quality, Minewater from East Ballarat Workings

Parameter	Concentration (mg/l)	Allowable Discharge Level
Iron	80-100 mg/l	1.00 mg/l
Arsenic	6-10 mg/l	0.05 mg/l
Manganese	0.8-1.2 mg/l	0.10 mg/l
Conductivity	3500-4000 µS/cm	1600 µS/cm
Fil. Residue	2000-2200 mg/l	1000 mg/l
Sodium	400 mg/l	-
Calcium	70 mg/l	-
Chloride	850 mg/l	-
Sulphate	400 mg/l	-

MINEWATER TREATMENT

Batch and Pilot Scale tests indicated that treatment consisting of aeration, filtration and polishing would reduce iron, arsenic and manganese concentrations in the minewater to levels acceptable for discharge into the Ballarat creek System.

Aeration converts the soluble ferrous ion into the insoluble ferric ion which precipitates as a typical 'red mud'. As part of this precipitation process, the ferric ion scavenges arsenic and to a lesser extent manganese, so reducing the soluble concentrations of these materials.

SALINITY CONCERNS

The salinisation of the agricultural lands and waterways of Victoria are significant and increasing problems. The treatment process has a negligible effect on salinity levels in the minewater. Ballarat has a distinctly seasonal climate, often characterised by dry summers. At such times the natural discharge in Canadian and Yarrowee Creeks becomes small and may cease altogether. In these circumstances, treated minewater discharges would form the major component of base flow. Whilst the salinity load of the treated minewater is small in overall terms, it would contribute to downstream salinity problems.

With respect to the disposal of treated minewater, the EPA required that the salinity of Yarrowee Creek water did not exceed 1000 mg/l at a location some 300 m downstream of the sewage effluent outfall (see Figure 1).

SALINITY DISPOSAL OPTIONS

Three disposal strategies were examined to meet the above salinity requirement: evaporation, de-salination and dilution. The first two strategies proved infeasible.

With respect to dilution, two potential sources of dilution water were available: treated sewage effluent discharged from the South Ballarat STP (see Figure 1) and surface runoff in the Ballarat Creek system after rainfall events.

Dry and wet weather discharges at the South Ballarat STP are about 12 ML/d and 40 ML/d respectively. The salinity of the sewage effluent under dry weather conditions is about 600 mg/l. A simple mass balance indicates that under dry weather flow conditions, up to 3.2 ML/d of treated minewater could be disposed of without exceeding the EPA salinity limit of 1000 mg/l.

The catchment area to the confluence of Yarrowee and Canadian Creeks is 104 km^2 of which 41 km^2 is controlled by four water supply dams. Of the remaining 63 km^2, some 19 km^2 consists of the urban area of Ballarat. Thus, a considerable area generates surface runoff for potential dilution purposes. Because of the significant urban area, discharges in the Ballarat creek system rise, peak and die away quickly during runoff events. The salinity of runoff water is quite low at about 100 mg/l.

Extensive numerical modelling studies indicated that a combined strategy of continuous low releases and intermittent high releases would provide a satisfactory means of disposal for the treated minewater. A continuous low level of release could be made for dilution by sewage effluent. Excess treated minewater could be pumped to storages at Site 'B' for holding and subsequent release during runoff events.

SALINITY MANAGEMENT SYSTEM

An automatic, real-time, computer-based salinity management system was developed firstly to monitor salinity levels in Yarrowee Creek, and secondly, to control the release of treated minewater into Canadian Creek at Sites 'A' and 'B'.

Monitoring Points

Table 2 shows details of the various monitoring points in the salinity managment network. The locations of these points are shown in Figure 1.

Table 2 Monitoring Locations, Ballarat Salinity Control System

Waterbody	Location	Parameter
Treated	Site 'B' Groundwater	Discharge
Treated Groundwater	Site 'A'	Discharge Salinity
Yarrowee Crk	Hill Street	Discharge Salinity
Sewage Effluent	STP	Discharge
Yarrowee Crk	Downstream STP	Salinity

Data Recorders

Electronic data recorders were installed at Site 'A', Site 'B', Hill Street and at the STP. Water levels are sensed with either a float and shaft encoder system or with a pressure transducer. Torroidal coils are used to sense salinity levels. Rating curves based on sharp crested weirs and open channel sections are used to convert water level data into discharge estimates.

Power and Communications

The data recorders are powered by re-chargable batteries connected to solar panels. Each recorder is linked by telephone to a central computer located at Site 'A'. The system is controlled by a IBM compatible PC AT computer. Each hour the computer automatically dials and interrogates the recorders and stores water level and salinity data away on 'hard disk'.

Control of Treated Minewater Discharges

The computer controls the discharge of treated minewater to Canadian Creek at Sites 'A' and 'B' under both 'low flow' and 'runoff' conditions.

During times of 'low flow', it takes some 8 hours for treated groundwater discharged into Canadian Creek at Site 'A' to arrive at the STP outfall and be diluted. Each hour, the computer forecasts the STP outflow 8 hours in advance and adjusts pumping rates at Site 'A' to ensure that salinity levels in Yarrowee Creek remain less than 1000 mg/l at the nominated monitoring point. (A simple forecasting procedure was developed that reflects the effects of wet weather inflows and the diurnal variation in sewage effluent discharge).

During times of runoff in the Ballarat Creek system, the computer estimates how much treated groundwater can be released from storages at Site 'B'. This is done on the basis of discharge and salinity levels in Yarrowee Creek at the Hill Street Site (see Figure 1). This release will be effected via sluice gates. The computer estimates the allowable discharge every 15 minutes. When the 'natural' flow in Yarrowee Creek falls below 1 m^3/s, the computer signals that discharge from the storage should cease.

Computer Program

A user friendly menu-driven computer program written in TURBO-PASCAL is used to operate the salinity monitoring and control system. Menu items are listed below:

1. Current Discharge and Salinity Values
2. Current Pump Status
3. Allowable Discharge
4. Report Menu
5. File Menu
6. Station Parameters
7. Pump Parameters

Item 1 obtains current discharge and salinity readings from the various monitoring sites.

Item 2 reports on the current status of the pumps at Site 'A': which pumps are on, the duration of the ON-OFF cycle, etc.

Item 3 shows the allowable discharges at Sites 'A' and 'B'. Low flow discharge estimates are based on dilution by sewage effluent at the STP. High flow discharge estimates are based on discharge and salinity in Yarrowee Creek at Hill Street.

Item 4, the report menu, enables daily, weekly and monthly reports to be printed for all stations. These reports are in a format that is suitable for direct submission to the EPA.

Item 5, the file menu, enables data files to be backed up and copied to floppy disk. This option is used to produce a floppy disk of hourly data that can be directly transferred to the EPA's computers.

Items 6 and 7 are used to set station parameters (salinity calibration, discharge rating curves, etc.) and pump parameters (nominal discharge, minimum ON and OFF times, etc.).

Should a break in power occur, the computer program will automatically reload and recommence operation when power is restored. The program incorporates a variety of 'alarm' features to alert operators of excessive salinity levels, communication difficulties, operational problems with pumps, etc.

Problems

Various problems were encountered in the development of the salinity managment system. Some were hardware related, e.g. the failure of a re-chargeable battery, the fouling of salinity sensors with weed, etc. An intermittent fault in a telephone 'modem' was both time consuming and frustrating to find. Software faults were more limited in nature: the software underwent major revisions and expansions several times during the first year to take full advantage of the flexibility of a computer operated system.

CONCLUSIONS

Various options were investigated for the disposal of saline minewater from the old workings of the East Ballarat Goldfield. After extensive numerical studies, it was concluded that a disposal strategy comprising the discharge of treated minewater to Canadian Creek for subsequent dilution by sewage effluent or by runoff from rainfall events would be practical, effective and meet EPA salinity level requirements.

A comprehensive salinity management system was developed to monitor salinity and to control the release of treated minewater to Canadian Creek. The system consists of a central computer linked by telephone lines to four automatic data recorders that measure discharge and/or salinity. The system is 'driven' by menu-based software that enables the automatic collection and storage of discharge and salinity data and facilitates the preparation of data reports.

Advantages of the salinity management system are its automatic nature, its reliability (after initial problems) and the relatively low level of human intervention. In addition, it facilitates the collection and transfer of data to the EPA, as required in the discharge licence conditions.

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

RECLAMATION OPTIONS FOR ACID MINE DRAINAGE AT HIGH-ALTITUDE METAL MINING SITE, NEAR FAIRPLAY, COLORADO

Anne Eckert Clift[1]

ABSTRACT

As part of Colorado's effort to fulfill the requirements of Section 319 of the Clean Water Act, a plan to reclaim the South Mosquito Creek area is being developed. The site is located in the Mosquito Range about nine miles northwest of Fairplay and eight miles east of Leadville, Colorado. The major contamination in the creek is a result of acid mine drainage from the abandoned London Extension Tunnel portal. The difficulty of planning reclamation in this area is increased by the extreme elevation (11,500 ft msl) and the presence of an active mine in a tunnel connected to the draining portal.

Approximately 75 gpm is draining from the abandoned London Extension Tunnel. The drainage, which contains as much as 39 mg/l of zinc and 42 mg/l of iron, has virtually eliminated aquatic life in South Mosquito Creek. The methods which have been considered for controlling and/or treating this drainage include hydrologic controls, passive mine drainage treatment systems, and active treatment systems. The applicability of various hydrologic controls including water-tight bulkhead seals, air seals, and infiltration barriers was examined with respect to the site conditions. Upon evaluation, none of these controls was considered to be feasible due to the current and future plans of the active mining operation 175 feet below the draining portal and the steep talus-covered terrain under which the extensive mining in the complex has occurred. Aeration, neutralization, wetlands, chemical adsorption, and biosorption were evaluated as possible passive mine treatment methods. Of these, all are thought to be adaptable to the conditions at the site. Active treatment systems were not considered feasible at this site because of the difficulty of site access during the winter months. At this time, further investigation is focused on the passive mine drainage treatment options. These include biosorption through immobilized biomass, limestone neutralization, wetland installation in a solar-heated building, chemical adsorption using zeolites, and aeration.

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[1] Colorado Department of Natural Resources, Mined Land Reclamation Division, 1313 Sherman Street, Room 215, Denver, Colorado.

INTRODUCTION

A plan to reclaim the South Mosquito Creek area located in the Mosquito Range in Park County, Colorado is being developed as part of Colorado's effort to fulfill the requirements of Section 319 of the Clean Water Act (Colorado Mined Land Reclamation Division, 1989). Studies have indicated that aquatic life in South Mosquito Creek, approximately nine miles northwest of Fairplay and eight miles east of Leadville, is essentially nonexistent as a result of the poor water quality and degradation of the habitat due to the extensive mining operations during the late 1800's and early 1900's (Colorado Department of Health, 1988).

The major contamination in South Mosquito Creek is the result of acid mine drainage from the abandoned London Extension Tunnel. This drainage is of relatively low pH and contains high concentrations of heavy metals, which result in an inhospitable environment for the aquatic life. The difficulty of designing reclamation plans in this area is increased due to the elevation of the site and the presence of an active mine onsite. Numerous reclamation options were investigated for containment and/or treatment of the contaminated drainage from the London Extension Tunnel. In this paper, these options and their applicability to the London Extension Tunnel site are reviewed and discussed.

GEOLOGY AND MINING HISTORY

The London Extension Tunnel is part of the London Mine, which forms a large northwest trending complex of interconnected drifts and tunnels under London Mountain, as shown in Figure 1. At the northwest end of the complex is the North London Mine portal. At the southeast end of the complex are the Water Tunnel, Ophir Tunnel and London Extension Tunnel portals.

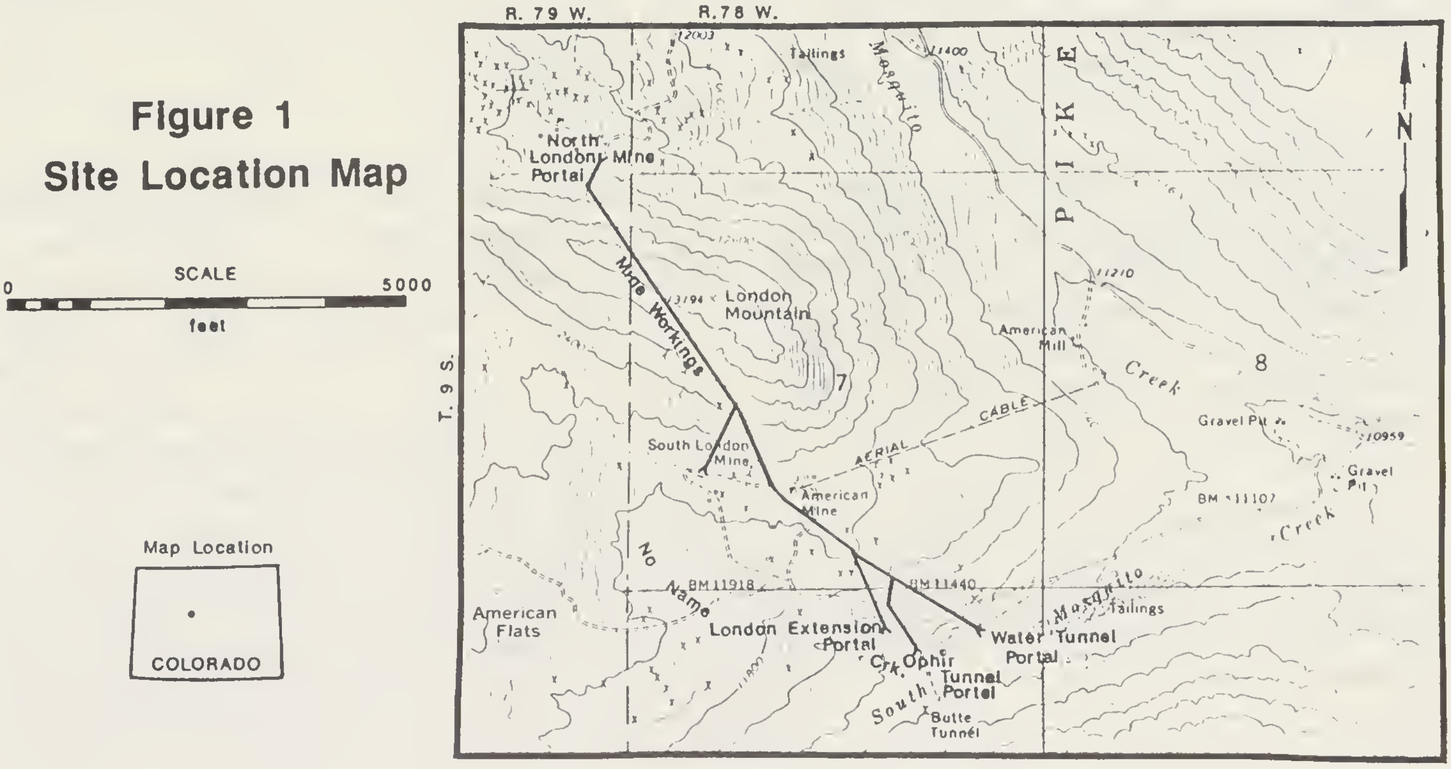

Figure 1
Site Location Map

The London gold vein was discovered in 1873 and mining began at the North London Portal in 1875. The primary ore body is located along the London Fault, which is a large reverse fault trending approximately N 30° W and dipping from 60° northeast to vertical with an estimated total offset of 3000 feet (Singewald, 1947). Precambrian schist and gneiss on the east side of the fault are juxtaposed against Paleozoic limestone, dolomite and quartzite on the west side of the fault. The major ore production has come from contact zones between Tertiary intrusive sills in the fault vicinity and Paleozoic sedimentary rocks. The total gross production of gold and silver until 1931 was recorded at almost $8,000,000 (Singewald and Butler, 1941).

In the 1970's, there were several attempts to continue mining in the lowest tunnel of the complex, known as the Water Tunnel, which daylights on the south side of London Mountain. The current operation, the London Mine Venture, has been mining the Water Tunnel since 1981. Although the company ceased operations temporarily in June 1989 due to declining gold prices, they intend to reopen as soon as possible. The future mining plans of this company include mining through London Mountain at the Water Tunnel level along the London Fault to the North London area (see Figure 1).

CLIMATE AND VEGETATION

The London Extension Tunnel lies at an elevation of approximately 11,500 feet, which in this area is about tree line. The winter season lasts from about November to April with an average annual snowfall of about 279 inches. Average annual precipitation is about 23 inches. Minimum and maximum temperatures recorded at a nearby weather station range from -25°F to 75°F (U.S. Department of Commerce, 1977-88). Snowmelt is heaviest during the months of May, June, and July. The dominant trees below tree line include Engelmann spruce, sub-alpine fur, lodgepole pine, and aspen. Above tree line, high-altitude species of grasses, forbs, and shrubs predominate. Willow bushes and grasses cover the valley floors.

HYDROLOGY

The lowest workings of the London Mine complex are the London Extension Tunnel and the Water Tunnel. Therefore, all mine drainage flows toward these openings passing through numerous abandoned stopes and drifts. Although the London Extension Tunnel is about 175 feet higher in elevation than the Water Tunnel, the workings are located such that little of the drainage from the London Extension Tunnel enters the active mine in the Water Tunnel. As a result, most of the drainage which flows through the abandoned workings exits the mine through the London Extension Tunnel. Currently, this flow enters a PVC pipe at the portal and is piped west into No Name Creek, which joins South Mosquito Creek approximately 1000 feet downstream.

Water flowing from the London Extension Tunnel at the portal was sampled and tested by the Colorado Department of Health in 1988 and 1989. The average flow from the portal is 75 gpm and the drainage was found to contain high concentrations in cadmium, copper, iron, manganese and zinc. The sampling results are listed in Table 1. Many of the metal concentrations measured during the May 1989 sampling show lower values than the August 1988 sampling due to increased dilution from spring runoff. Also listed in Table 1 for comparison are the Chronic Criteria for the Protection of Coldwater Aquatic Life for No Name Creek above the point where drainage from the London Extension Tunnel enters the creek.

TABLE 1: WATER QUALITY AT LONDON EXTENSION TUNNEL PORTAL
(Colorado Department of Health, 1988, 1989)

CONSTITUENT	DATE SAMPLED				CHRONIC STANDARDS*
	August 30, 1988		May 10, 1989		
pH	4.74		6.50		6.5-9.0
Sus. Solids (mg/l)	91.		160.		-
Sp. Cond. (umhos)	1020.		-		-
Aluminum (mg/l)	Tot:1.2	Dis:<1.0	Tot:1.8	Dis:<1.0	Dis:0.15
Cadmium (mg/l)	Tot:0.15	Dis:0.15	Tot:0.083	Dis:0.05	Dis:0.001
Copper (mg/l)	Tot:0.95	Dis:0.83	Tot:0.59	Dis:0.009	Dis:0.01
Iron (mg/l)	Tot:42.	Dis:3.4	Tot:42.	Dis:<0.1	Tot:1.0
Lead (mg/l)	Tot:0.008	Dis:<0.005	Tot:0.037	Dis:<.005	Dis:0.003
Manganese (mg/l)	Tot:2.9	Dis:2.7	Tot:1.6	Dis:1.4	Tot:1.0
Zinc (mg/l)	Tot:39.	Dis:40.	Tot:18.	Dis:12.	Dis:0.045

* Chronic Standards for the Protection of Coldwater Aquatic Life are given for No Name Creek above where drainage from the London Extension Tunnel enters the creek.

A cross section of the London Mine complex is shown in Figure 2. Two raises connect the London Extension level with the lower Water Tunnel level. Some of the stoping in the complex is shown on this cross section, although it is doubtful that the available maps were entirely accurate in this respect. It appears that the mine drainage flowing from the London Extension Tunnel originates from flow through the talus and bedrock of London Mountain. Although a considerable amount of water also drains from the Water Tunnel, the predominant source of this water is flow from exploration drillholes. As a result, this water has been found to be of higher quality than drainage from the London Extension Tunnel.

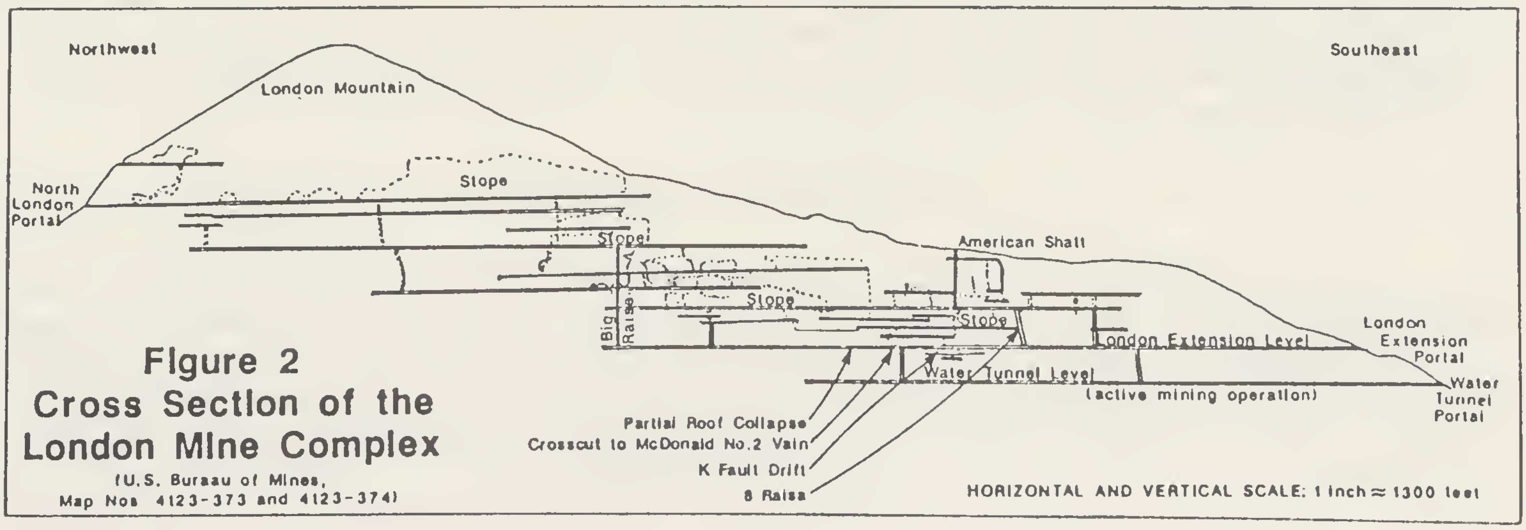

Figure 2
Cross Section of the London Mine Complex
(U.S. Bureau of Mines, Map Nos 4123-373 and 4123-374)

Figure 3 shows a map of the workings on the London Extension level. The points marked Water Raise and Escapeway are the connections to the lower actively-mined Water Tunnel. The drifts are inclined in these areas such that very little water flows into the lower workings from the London Extension Tunnel. The point marked Big Raise connects the London Extension level with the upper workings in the complex (see Figure 2).

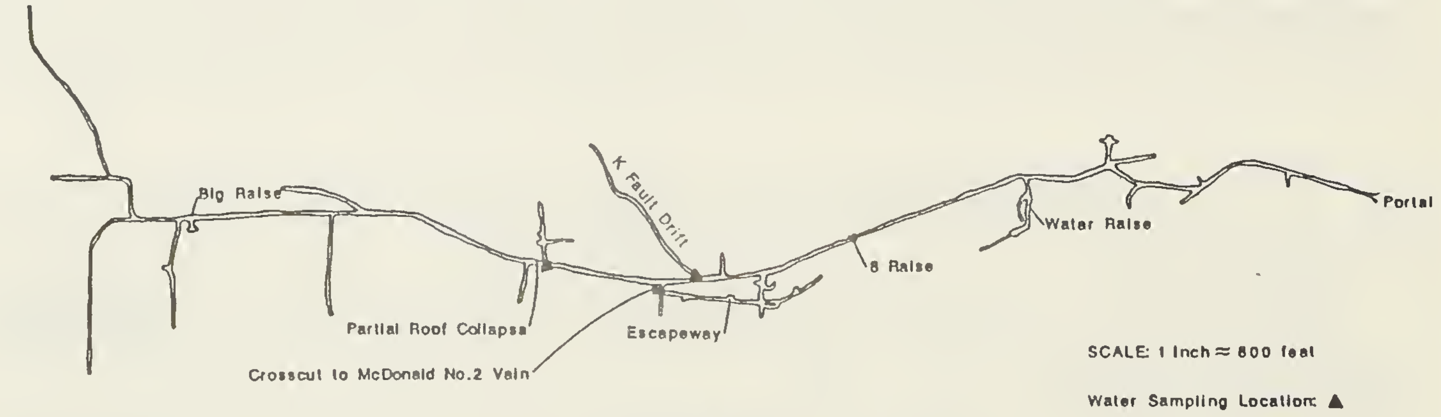

Figure 3
London Extension Tunnel Workings
(Map Provided by London Mine Venture)

A reconnaissance of the London Extension Tunnel level was conducted in July 1989 and progressed approximately 3000 feet into the main tunnel to the partial roof collapse shown in Figures 2 and 3. At this point, the quantity of flow in the tunnel was estimated to be 200 gpm. (The loss of approximately 125 gpm of water between this point and the portal is assumed to be due to seepage and drainage into the lower workings.) Some drainage (less than 10 gpm at each site) was flowing into the main drift from the 8 Raise, the K Fault Drift, and the Crosscut to McDonald No. 2 Vein. Water samples were collected at that time from the main drift at the partial roof collapse, the K Fault Drift, and the Crosscut to McDonald No. 2 Vein. These locations are shown in Figure 3. The results of these tests are shown in Table 2 and indicate that the primary source of water through the main Extension Tunnel (at the partial roof collapse) is not the primary source of contamination. In fact, the small amounts of water draining from the Crosscut to McDonald No. 2 Vein and the K Fault Drift are extremely highly concentrated in heavy metals and very low in pH. The toxic water flowing through the main tunnel (as tested at the partial roof collapse) is actually acting to dilute these more toxic inflows.

RECLAMATION OBJECTIVES

The primary reclamation objective for the drainage from the abandoned London Extension Tunnel is to decrease or remove the harmful effect it is having on the surface water system. This could either be accomplished by preventing the drainage from entering the surface water system or by treating the drainage to remove the toxic constituents.

TABLE 2: WATER QUALITY IN LONDON EXTENSION TUNNEL WORKINGS

PARAMETER	SAMPLE LOCATION Partial Roof Collapse	 Crosscut to McD. No.2 Vein	 K Fault Drift
Est. Flowrate (gpm)	200	5	5
pH	7.1	2.8	2.4
Conductivity (umhos/cm)	700	2371	4404
Aluminum (Total, mg/l)	0.1	4.1	17.7
Cadmium (Total, mg/l)	0.02	0.42	1.73
Copper (Total, mg/l)	0.10	3.45	11.4
Iron (Total, mg/l)	3.42	80.40	407.
Lead (Total, mg/l)	<0.05	0.16	0.44
Manganese (Total, mg/l)	0.59	6.06	13.5
Zinc (Total, mg/l)	5.04	85.10	333.

RECLAMATION ALTERNATIVES

The major obstacles for reclamation at the London Extension site are the extreme climatic conditions and the active onsite mining. Given these two concerns, various options have been investigated for the treatment or containment of the drainage.

Hydrologic Controls

Bulkhead Seals

Water-tight bulkhead seals are designed to 1) contain the contaminated water in the mine, preventing its direct entrance into the surface water system; and 2) inundate acid-producing materials in the mine, thereby reducing the production of sulfuric acid. After investigation, it was concluded that this option is currently not feasible at this site for the following reasons.

- There are at least two open portals connected to the Extension level which lie below the Extension Tunnel in elevation. These include the Ophir and Water Tunnels, which are about 175 feet lower than the London Extension Tunnel. At this time, the Ophir Tunnel is not used, however the Water Tunnel is the main access for the operating London Mine Venture. The future plans of the London Mine Venture are to mine at the Water Tunnel level northwest through London Mountain. If a bulkhead was placed in the Extension level, drainage from the abandoned mine workings would be forced to flow through the Water Tunnel.
- The London Extension Tunnel is currently used for ventilation and as an escapeway for the active mine in the Water Tunnel. A bulkhead seal would undoubtedly alter the ventilation system for the active mine.

Air Seals

Air sealing of the mine workings by partial bulkheading is used to create a low-oxygen environment in the mine, which reduces the production of sulfuric acid. In the case of the London Extension Tunnel, the connected workings are very extensive and lie below a steep talus-covered peak in highly fractured and faulted rock. This situation makes the mine very difficult to seal. In addition, sealing was not considered further because the active mine operation uses the tunnel for ventilation and as an escapeway.

Infiltration Barriers

Infiltration barriers include methods of preventing or reducing uncontaminated water from infiltrating into abandoned mine workings, and thereby becoming contaminated. Because water entering the London Mine complex is thought to infiltrate through London Mountain and because the workings are so extensive, infiltration barriers were not considered feasible at this site.

Passive Treatment of Mine Drainage

Based on the available hydrologic information, one option for passive treatment of the mine drainage from the London Extension Tunnel is installation of a system to treat the entire flow (average: 75 gpm) from the portal. A second option involves treatment of only the highly contaminated flows from the K Fault and Crosscut to McDonald No. 2 Vein (average: 10 to 20 gpm). In the latter case, it would be necessary to collect the highly contaminated water at its discharge points inside the mine and pipe it to the treatment system. In that way, intermixing with the less contaminated drainage in the main drift of the Extension Tunnel would be avoided.

Aeration

Aeration of the drainage provides a means of increasing the amount of dissolved oxygen in the drainage, thereby increasing the pH and causing some of the metals to precipitate. This could be accomplished in the area directly outside of the Extension Tunnel portal by constructing a long, lined drainage ditch with several hydraulic jumps. Periodic maintenance to remove and dispose of precipitated metals would be required.

Neutralization

Neutralization of the pH in the drainage will cause precipitation of some of the heavy metals. Two methods of accomplishing this include using lime or limestone. The use of powdered lime in such a system was not considered feasible at this site, because continual attention is required to add the lime in the correct proportions for the flowrate. The other method involves the use of limestone ground to 5 to 10 microns. Limestone this size dissolves nearly completely when added to acid mine drainage and can effectively raise the pH in the drainage. A major drawback to either system is the production of sludge, which must then be properly neutralized for disposal.

Wetlands

Wetlands, as a treatment system for acid mine drainage, increases the pH of the water and removes heavy metals through biological processes. The major obstacle for a wetland at the London Extension site is the extreme climatic conditions. As the temperatures decrease, wetlands become less effective in treating the drainage. One option is to shelter the wetland system in a building maintaining proper temperatures using solar power. The second option is to locate the wetland inside the London Extension Tunnel. Inside the mine, a 'wetland' would be subjected to constant temperatures of between 40 and 50 degrees. Work at the Big Five Tunnel in Idaho Springs, Colorado, has suggested that an efficient substrate is most important in removing the heavy metals from acid mine drainage and a lack of plants (due to lack of light) should not lessen the effectiveness of the system (Personal Communication with Dr. Ronald Cohen, Colorado School of Mines). Maintenance of either type of wetland would require periodic replacement of the substrate when it becomes saturated. The substrate material would then be considered as a contaminated sludge and would require proper disposal.

Although technically possible at the site, the in-mine 'wetland' is not considered a feasible alternative for the following reasons:

- When the London Mine Venture operation resumes work, their ventilation system will decrease the ambient temperature of the London Extension Tunnel during the winter. The in-mine 'wetland' would then be subjected to freezing temperatures which would adversely affect its treatment efficiency.
- The cramped conditions inside the mine tunnel make replacement of the saturated substrate a labor-intensive and therefore costly operation.

Chemical Adsorption

Chemical adsorption through ion exchange of the metals in the acid drainage was considered using natural onsite geologic materials and zeolites.

The clay in the natural glacial till in a small hill just south of the London Extension Tunnel was considered to be the most feasible option for performing ion exchange. The system would require piping the contaminated drainage into an unlined sedimentation pond located on the till. As the water seeps through the till, the metals would be adsorbed onto the clay. To evaluate the feasibility of such a system at this site, two five-foot deep holes were excavated in the till. The soils consisted of sandy gravel with cobbles and only a small amount of clay. Percolation tests in the holes indicated that the soils were very permeable (average value: 0.7 min/in). In addition, the cation exchange rates for the soils were low (average value: 8.3). The conclusion from these tests is that till in the vicinity of the London Extension Tunnel does not contain enough clay to make this type of system workable.

A zeolite system for ion exchange in the treatment of acid mine drainage has been found to work best at pH's of 5.5 to 6, based on tests performed by Boulder Innovative Technologies in conjunction with the Colorado School of Mines (Personal Communication with Mr. Bruce Stover, Colorado Geological Survey). Because of this, a zeolite system would be incorporated as a polishing component following primary treatment of the drainage by another means, such as limestone neutralization.

Biosorption

The adsorption of metals from acid mine drainage onto different types of biomass has been extensively studied and proven to be successful in many cases (ie., wetlands). A system has been developed whereby immobilized biomass is incorporated into porous plastic beads. The biomass adsorbs heavy metals from acid drainage through ion exchange as the flow seeps through the beads. The primary advantage of this system is that it does not produce sludge. The metals collected from the drainage can be stripped off the beads using a dilute acid solution and processed for use in metal products. Following stripping, the beads can be reused.

Two of these types of systems are currently available. One of these systems (BIOCLAIM) is sold commercially by International Process Research Corporation in Golden, Colorado, however, the efficiency of this system is reported to be low in winter temperatures such as those expected at the London Extension Tunnel. The other system (BIO-FIX) is currently being researched by the U.S. Bureau of Mines (Jeffers, et.al., 1989). Laboratory studies have indicated that metal ions can effectively be extracted by this system at temperatures such as those expected during the winter at the London Extension Tunnel.

Because this type of system works best at pH's between 4 and 6, treatment of all the flow from the portal (average pH: 5.6) appears to be the best option. Samples of the drainage from the portal were tested to evaluate the potential use of BIO-FIX at the London Extension site. Initial concentrations were recorded at 1.1 mg/l copper, 56 mg/l iron, 4 mg/l manganese, and 41 mg/l zinc. Preliminary results indicate reductions of 98% in copper, 95% in iron, 98% in manganese, and 99% in zinc.

The use of BIO-FIX to treat the drainage from the London Extension Tunnel would require periodic maintenance. The BIO-FIX beads will become saturated with heavy metals through time and therefore less efficient. The frequency of saturation depends on the amount of flow from the portal, the concentration of metals in that flow, and the amount of BIO-FIX in the treatment system.

Active Mine Drainage Treatment

Active mine drainage treatment systems, such as microbial ponds, chemical coprecipitation, and continuous concentration were not considered to be feasible for the London Extension site. The problem of access for continual operation and maintenance of an active treatment facility is difficult and costly in these extreme climatic conditions.

CONCLUSIONS

Numerous options for the treatment of acid mine drainage at a high-altitude metal mining site have been investigated. These include hydrologic controls and passive treatment systems. Active systems were not considered feasible due to access problems during the severe winters. Options were also limited because of the presence of an active mine onsite. Based on the current knowledge of the London Extension Tunnel site, the most feasible reclamation alternatives include biosorption through immobilized biomass, limestone neutralization, wetland installation in a solar-heated building, chemical adsorption using zeolites, and aeration.

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Planning, Rehabilitation and Treatment of Disturbed Lands
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PERFORMANCE OF A NATURAL WETLAND ON CONTROL OF ACID MINE DRAINAGE FOR 50 YEARS

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ABSTRACT

A natural wetland in western Montana received acid mine drainage (AMD) from an abandoned lead/zinc mine for at least 50 years. The wetland was effective in removing iron (550 mt) from AMD, but was less effective in removing manganese (1 mt) and other metals. Water velocity through the wetland averaged 2.6 x 10^{-2} cm/s (74 ft/day) and had a water residence time of approximately nine days. During 50 years of AMD, a sedge peat substrate of 22,620 m^3 covering an area of 3.9 ha (9.8 acres) became saturated with metals. Tissues of plants growing in this wetland contained elevated metal levels compared to a control wetland not exposed to AMD. Metal levels in plant tissues exceeded the maximum dietary intake level for domestic animals, but were not considered a risk to wildlife in the area. Sulfate reducing bacteria were present in the natural wetland that received AMD, but were present at comparatively low levels in a man-made wetland constructed to treat AMD. Poor performance by the man-made wetland may, in part, be due to reduced microbial activity.

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[1] This investigation was funded by the Montana Abandoned Mine Reclamation Bureau, Helena, Montana. Contents of this paper have been summarized from technical reports (RRU 8804 and 9001) available from the Reclamation Research Unit, Montana State University, Bozeman, Montana.

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INTRODUCTION

Hydrogeochemical, vegetational, and microbiological characteristics were studied in a wetland that received at least 50 years of AMD. These findings will be useful to those involved in the design of man-made wetlands to treat AMD.

The Swamp Gulch natural wetland continues to receive AMD from the abandoned Carbonate Mine where lead and zinc ore were extracted during the 1930s (Figure 1). For purposes of comparison, a control natural wetland (i.e. no AMD) on Hardscrabble Creek and a man-made wetland located near Sand Coulee, Montana for treatment of AMD were included in this study.

In order to make this paper concise, methods associated with investigation design, instrumentation, sampling, laboratory analysis, statistical analysis, and quality control are not presented. These methods are presented in detail in Dollhopf et al. (1988) and Zavitz et al. (1990). A portion of the results in these two reports are presented below.

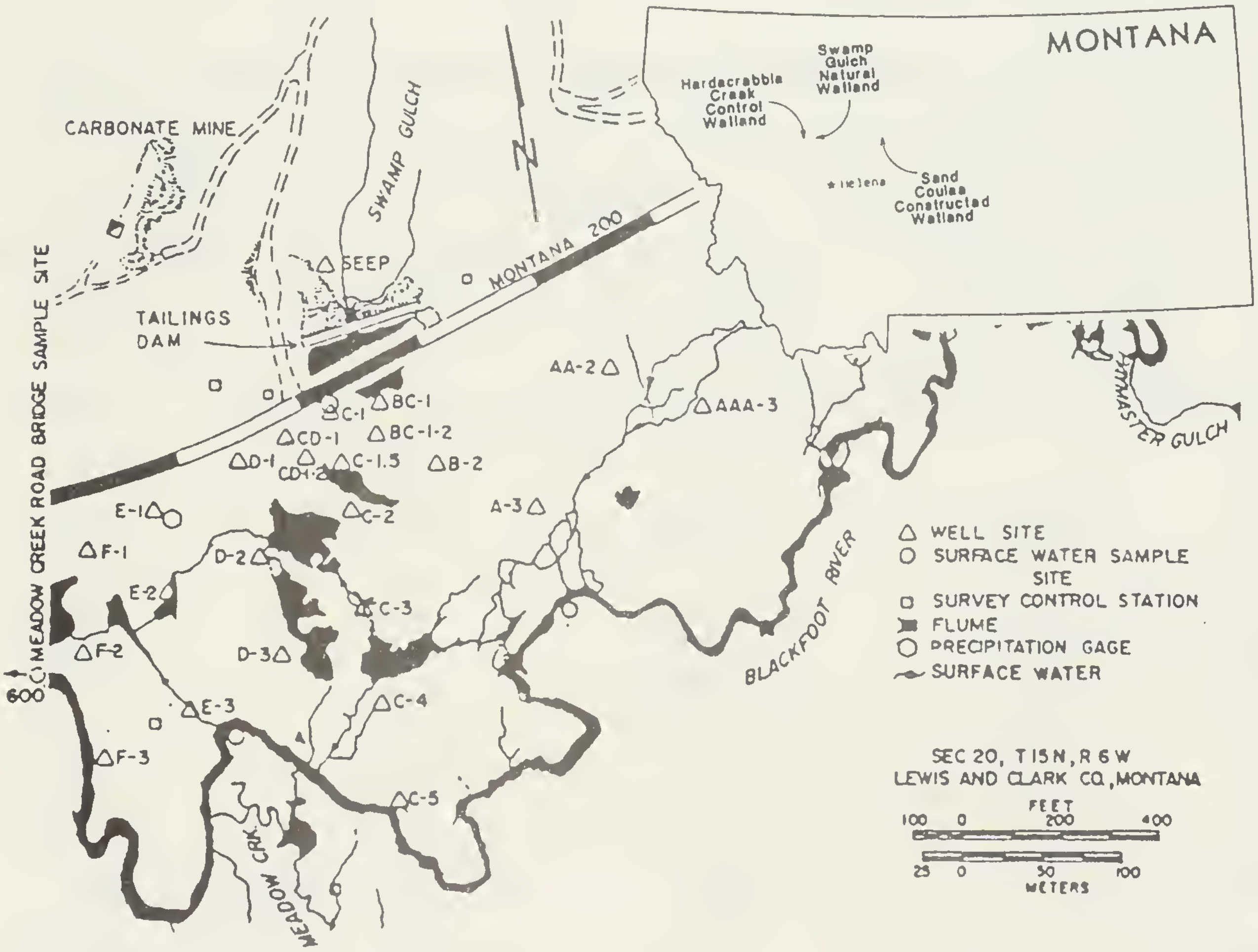

Figure 1. Location of wetland sites (inset) and surface details of the Swamp Gulch natural wetland.

WETLAND EFFECTIVENESS AFTER 50 YEARS

During 1987, average flow of AMD into the Swamp Gulch natural wetland was 45 m^3/day (8.2 gal/min). AMD from the Carbonate Mine typically had a pH 3, high levels of SO_4 and TDS, and numerous enriched metals (Table 1). Prior to entering the wetland, AMD mixed with good quality water in the Swamp Gulch channel, resulting in partial dilution of the AMD chemistry.

Using wells (piezometers) and bromide tracer techniques it was determined that most of the water entering the wetland moved through an upper zone (.24-1.04 m thick) of undecomposed organic matter (acrotelm) permitting an average flow velocity of 2.6×10^{-2} cm/s (74 ft/day). Muck, 0.58-4.3 m thick was present beneath the acrotelm and had much slower flow velocities compared to the overlying fibrous organic material zone.

During the past 50 years, AMD impacted approximately 3.9 ha (9.6 acres) of the acrotelm zone in the Swamp Gulch natural wetland. Based on water and sediment analyses, it was estimated that water was flowing a distance of as much

Table 1. Chemistry of surface water entering and exiting the Swamp Gulch natural wetland.

Parameter	Above Carbonate Mine in Swamp Gulch (background)	Carbonate Mine AMD (Seep D)	Swamp Gulch Water + AMD Mix Entering Wetland	Below Impacted Wetland (Station F-1)
TDS, mg/L	74	1730	282	255
Al, mg/L	<0.1	3.6	6.2	0.4
As, mg/L	<0.005	<0.005	<0.005	<0.005
Ca, mg/L	12.7	229	22	26
Cd, mg/L	0.001	0.236	0.038	<0.001
Cu, mg/L	<0.01	0.65	0.61	0.04
Fe, mg/L	0.7	47.3	25.8	15.1
Pb, mg/L	<0.01	0.20	0.035	<0.01
Mn, mg/L	0.08	61.1	3.73	4.30
Ni, mg/L	<0.03	0.10	0.37	<0.03
Zn, mg/L	<0.01	5.68	2.64	0.12
SO_4, mg/L	10.7	1213	212	142
pH	6.8	3	3.6	3.3
EC, mmhos/cm	0.1	2	0.5	0.4

[1] Values are means from three sampling dates: 4/29/87, 7/28/87 and 1/11/88.

as 200 m before the wetland completed amelioration of the water chemistry. Given these dimensions and the acrotelm flow velocity, the calculated AMD residence time in the wetland was approximately nine days.

Chemical analysis throughout the solid fraction in the Swamp Gulch wetland acrotelm enabled a calculation of the total metal loading from AMD since the inception of mining approximately 50 years ago (Table 2). Also presented in Table 2 is the AMD input of various metals during a 12 month period in 1987-1988. Given the 1987-1988 annual AMD input for Mn (.0634 mt/year), and assuming that this input rate during the past 50 years was equal to or greater than the 1987-1988 rate, the acrotelm zone contained only a fraction of the Mn that was input by AMD during the 50 year period. Similarly, the acrotelm zone contained only a fraction of the Cd that was input by AMD during the 50 year period. These results indicate this natural wetland was not effective in removing Mn and Cd from AMD. Conversely, Cu, Fe, Pb, and Zn may have been effectively treated by this wetland as indicated by the metal mass in the acrotelm and the 1987-1988 AMD metal loading rate.

Table 1 shows chemistry levels in water leaving (Station F-1) the 3.9 ha area of wetland acrotelm that was impacted by AMD. These data indicate levels of Cd, Pb, and Ni were decreased to concentrations equivalent to background. Concentrations of Al, Cu, Fe, and Zn were all decreased by wetland treatment but remained above background levels. The Mn concentration leaving the wetland was similar to, actually higher than, that entering the wetland in AMD. These results tend to corroborate those derived from acrotelm metal loading

Table 2. Acrotelm total metal accumulation during the past 50 years and metal input from AMD in 1987-1988.

	Acrotelm metal mass	1987-88 Annual Input from AMD
	metric tons	
Cadmium	0.004	0.00054
Copper	3.8	0.0116
Iron	553	0.338
Lead	1.3	0.00054
Manganese	1.1	0.0634
Zinc	6	0.0436

calculations (Table 2). It should be noted that water sampled at Station F-1 may have been diluted somewhat from adjacent flow not emanating from the 3.9 ha impacted zone. This dilution effect may be the reason why acrotelm metal loading calculations indicated Cd was not effectively treated by the wetland, but Station F-1 indicated Cd water concentrations leaving the wetland were equivalent to background.

WETLAND VEGETATION

More than 23 plant types were identified in the Swamp Gulch natural wetland (Table 3). *Carex rostrata* was the dominant species throughout the study area. *Typha* (cattail) was not present. Herbaceous production on the Swamp Gulch wetland averaged 3820 (kg/ha) which was not significantly different ($p \leq .05$) compared to the pristine control wetland on Hardscrabble Creek (3750 kg/ha). This pristine wetland, which was not subjected to AMD, had vegetation composition very similar to the Swamp Gulch wetland.

Above and below ground plant materials were chemically analyzed for Al, As, Cd, Ca, Cu, Fe, Pb, Mn, Ni, and Zn. Several plant species contained enriched levels of elements compared to the control wetland (Table 4). These results are discussed in detail in Dollhopf et al. (1988). Plant concentrations of Cd, Cu, and Zn were of particular concern since these levels exceeded the maximum tolerable levels of dietary minerals for domestic animals (Tables 5 and 6). These high metal levels represent a possible hazard to the wildlife inhabiting this wetland. Predators such as weasel, fox, and raptors may be at risk when they feed on voles or mice if the carnivores habitat is largely within the impacted wetland. It was determined that Cd and Cu in kidneys of voles and Cd in whole bodies of shrews were significantly elevated in the AMD impacted wetland (Swamp Gulch) compared to the control wetland on Hardscrabble Creek. However, it was concluded that Cd and Cu were not accumulating to hazardous levels in voles or shrews or to be a risk to animals that prey on them.

SULFATE REDUCING BACTERIA

Sulfate reduction with resulting pyrite formation are biogeochemical processes that can improve wetland performance in treating AMD. In the absence of oxygen, bacteria oxidize organic matter and use sulfate as the electron acceptor, which results in sulfate being reduced to hydrogen sulfide [1] (Hedin

$$SO_4^{2-} + 2CH_2O(\text{i.e. organic matter}) \xrightarrow{\text{bacteria}} H_2S + 2HCO_3^- \qquad [1]$$

Table 3. Mean percent canopy coverage and percent frequency for plant species in the Swamp Gulch wetland.

Species	Life Form[1]	% Canopy Coverage	% Frequency
Carex rostrata	GL	55.5	90.4
Betula glandulosa var. hallii	S	11.3	31.7
Pinus contorta	T	6.3	8.7
Salix boothii	S	5.5	19.2
Sphagnum tenellum	M	4.7	12.4
Chimaphila umbellata	S	3.0	8.7
Potomogeton sp.	F	2.8	1.9
Isopterygium pulchellum	M	2.8	18.1
Pyrola asarifolia	F	1.2	7.6
Arctostaphylos uva-ursi	HS	1.1	5.7
Abies lasiocarpa	T	0.9	1.0
Juniperus communis	S	0.9	1.9
Picea engelmannii	T	0.9	4.8
Scirpus acutus	GL	0.9	1.2
Pseudotsuga menziesii	T	0.6	1.0
Equisetum sp.	F	0.5	11.5
Vaccinium scoparium	HS	0.3	1.0
Achillea millefolium	F	0.1	1.9
Elymus glaucus	G	<0.1[2]	1.0
Fragelia virginiana	F	<0.1	4.8
Festuca idahoensis	G	<0.1	1.0
Geum macrophyllum	F	<0.1	1.0
Phleum pratense	G	<0.1	1.0
Unknowns		2.2	1.0
	TOTAL	101.8	

[1] LF = Life Form: GL = Grasslike, S = Shrub, T = Tree, M = Moss, F = Forb, HS = Half-Shrub and G = Grass

[2] Values of <0.1 were tabulated as 0.05.

et al. 1988). The hydrogen sulfide either bubbles away as a gas or remains in the wetland as sulfides, polysulfides, elemental sulfur, iron monosulfide, and pyrite. This reduction process produces alkalinity (HCO_3^-), which decreases acidity and raises pH. Formation of metal sulfides removes iron from solution. These changes in water chemistry are primary goals in treatment of AMD. Therefore, sulfate reducing bacteria must be present in sufficient numbers in constructed wetlands to initiate and maximize this biogeochemical process.

Table 4. Plant species demonstrating element enrichment at the Swamp Gulch wetland site.

Plant Species	Enriched Elements In Above Ground Plant Material
Carex rostrata	Al, Cd, Cu, Fe, Pb, Zn
Salix boothii	Al, Cd, Cu, Fe, Pb, Mn, Zn
Betula glandulosa	Cd, Cu, Fe, Mn, Pb, Zn
Isopterygium pulchellum	Al, Cd, Cu, Fe, Pb, Mn, Ni, Zn

Table 5. Metal concentrations (μg/g) in vegetation[1] from the study site (Swamp Gulch wetland) and the background site (Hardscrabble Creek).

		Hardscrabble Creek		Swamp Gulch	
Element	Plant species	n	mean	n	mean
Cd	*Salix boothii*	2	0.6	6	5.6
	Carex rostrata	4	0.8	5	1.5
	Isopterygium pulchellum	1	0.7	4	7
Cu	*Salix boothii*	2	0.35	6	1.3
	Carex rostrata	4	3.8	5	62
	Isopterygium pulchellum	1	15	4	132
Zn	*Salix boothii*	2	130	6	388
	Carex rostrata	4	96	5	134
	Isopterygium pulchellum	1	44	4	1074

[1] Aboveground tissue

Table 6. Maximum tolerable levels[1] of dietary minerals for domestic animals (National Research Council 1980).

Element	Cattle	Rabbit
Cd	0.5	(0.5)
Cu	100	200
Zn	500	(500)

[1] All values are in $\mu g/g$ unless otherwise specified. Values in parentheses were derived by extrapolation.

Viable total microbial biomass and sulfate reducing bacteria biomass in wetlands were determined from extraction of cellular components using the phospholipid ester-linked fatty acid (PLFA) analysis technique (Guckert et al. 1985). Investigation methodology is presented in detail in Dollhopf et al. (1988).

Montana made its first attempt at wetland construction in 1986 at a site located near Sand Coulee (Figure 1). Hiel and Kerins (1988) described the man-made wetland designed to treat AMD of approximately 12 gal/min. They indicated the 400 m^2 (0.1 acre) wetland consisting of a peat substrate, *Typha latifolia* plant material, and limestone gravel and aeration structures was ineffective in improving water quality. The man-made wetland had 4 to 6-fold less microbial biomass at the 20-21 cm compared to natural wetlands (Table 7). The biomass of sulfate-reducing bacteria in the constructed wetland was 3.7 to 4 times lower compared to natural wetlands at the 20-21 cm depth. It should be noted that sulfate-reducing bacteria are obligate anaerobes which are considered to be terminal carbon users. Bacteria at this nutritional level rely on other aerobic and anaerobic degraders to generate the carbon and energy substrates required for sulfate-reducing bacterial growth (Dowling 1987). This synergistic relationship suggests the comparatively low microbial biomass of the constructed wetland may be limiting the presence of sulfate-reducing bacteria. This overall lack of microbial biomass may be one factor contributing to wetland ineffectiveness in treating AMD as concluded by Hiel and Kerins (1988).

In a general sense, it could be said the natural wetland and the constructed wetland had the same substrate, meaning peat. However, the man-made wetland consisted of a highly weathered peat soil hauled 250 miles to the Sand Coulee site. It was relatively free of fibrous plant material and may have been more representative of muck. Conversely, the acrotelm zone (.24-1.04 m

Table 7. Microbial biomass and sulfate reducing bacteria biomass in several wetlands at two sampling depths.

	Wetland Location		
		Receiving AMD	
Wetland Depth (cm)	Control	Swamp Gulch, Natural	Sand Coulee, Constructed
	Total Microbial Biomass, nmoles/g dry wt.		
1-2	ND	ND	14±6
20-21	37.1±4.2*	55.5±30.1	9.1±1.1
	Total Sulfate Reducing Bacteria Biomass, nmoles/g dry wt.		
1-2	ND	ND	1.2±1.0
20-21	3.6±0.5	3.4±1.6	0.9±.05

ND = Not Determined
* Mean ±1 standard deviation, n = 3.

thick) in the natural wetland was a sedge peat consisting largely of undecomposed plant material. The muck-like sediments used in the man-made wetland would have consisted of complex carbon sources not easily degraded by bacteria. The sedge peat consisted of viable plant materials and simple carbon compounds easily degraded by bacteria. It is likely that this scenario contributed to a much greater microbial biomass in the natural wetland where an energy source was much more easily attained compared to the muck-like substrate of the constructed wetland.

These results suggest wetlands should be constructed with a substrate consisting of simple carbon sources such as viable plant material. Such a substrate is beneficial to sulfate-reducing bacterial population.

LONGTERM FEASIBILITY OF MAN-MADE WETLAND

Wieder (1988) indicated the cost/benefit of man-made wetlands cannot be determined without being able to estimate long-term metal retention capacity. That is to say, man-made wetlands, typically 400-3000 m^2 (0.1-.75 acres), may be filled to capacity with metals long before AMD stops. Results from the Swamp Gulch natural wetland supports this concern pertaining to cost/benefit. During the course of 50 years of AMD, the 22,620 m^3 of sedge peat substrate covering an area of 3.9 ha (9.8 acres) was saturated with approximately 565 mt of metals from AMD. During 1987-1988, AMD discharge into the wetland was 43 m^3/day (8.2 gal/min) and although discharge was likely greater during active mining this flow rate is probably representative of the 50 year period. Most man-made wetland projects either completed or in planning addressed similar AMD flow rates (i.e. <10 gal/min) and costs tend to limit the final wetland size to less than 4000 m^2 (1 acre).

> *Given, 1) the chemistry of AMD entering the Swamp Gulch wetland is representative of sites where man-made wetlands have been constructed, 2) the large volume of sedge peat saturated by metals in the Swamp Gulch wetland during 50 years, and 3) that sulfate reduction biogeochemical processes were likely active in this natural wetland, the longevity of much smaller man-made wetlands would seem to be inadequate in most cases to treat AMD for decades of time.*

Engineers assigned wetland construction projects should thoroughly evaluate substrate capacity to retain metals. These calculations should be based on metal concentrations in the AMD, the AMD flow rate, and retentive capacity of the selected substrate.

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Billings Symposium, 1990

A PILOT-SCALE CONSTRUCTED WETLAND FOR TREATMENT OF METAL MINE DRAINAGE FROM THE BIG FIVE TUNNEL, CENTRAL CITY-IDAHO SPRINGS MINING DISTRICT, COLORADO

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ABSTRACT

A research project on the passive treatment of mine drainage has been underway since Fall 1987. Different mixtures of organic materials and limestone were placed into three lined cells, and a few species of vegetation were transplanted into the system. Mine drainage was distributed to the cells of the structure and access wells allowed sampling of interstitial water. Results of initial and subsequent studies led to further refinement of objectives and changes in design.

Several metals have been successfully removed from the mine waters. The pH of the cell outflows often exceeds 6 while the inflow of the mine drainage is near pH 3. Some of the metals are in sulfide form, but larger proportions are attached to reactive sites of the substrate and biota. Active sulfate-reducing bacteria are present in large numbers and the spatial distribution of sulfate-reducing and iron-oxidizing bacteria has been studied. The hydraulic conductivity of the system has been characterized and experiments in optimizing hydraulic parameters of the system are currently in progress.

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INTRODUCTION

The Idaho Springs-Central City mining district of the Colorado Front Range produced significant amounts of precious metal ores around the turn of the century. Abandoned mines and tunnels in the area continue to produce drainage with low pH and high metals concentrations that adversely impact the regional aquatic resources (Lewis, et al., 1987). As a result, several sites in the district are on the National Priorities List under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or Superfund). The Big Five Tunnel, used for haulage and dewatering the extensive workings of the southern portion of the district, is one of these sites.

Natural and artificially created wetlands have been observed to reduce metals concentrations and raise pH of acid mine drainage (Holm, 1983; Kleinmann, 1983). A demonstration treatment system was constructed in a closed configuration at the Big Five portal to investigate the fate of metals, to determine survival and metals uptake by vegetation, to study function and distribution of bacteria, and to optimize the hydraulic characteristics of the system. Based on the results of successive investigations, the initial research objectives have been revised and refined, along with appropriate changes in the design of system components.

INITIAL DESIGN

The initial concrete structure, 1.2 m deep, 3 m wide and 16 m long, was fitted with six drains and separated into three equal-sized, Hypalon^R-lined cells (Figure 1).

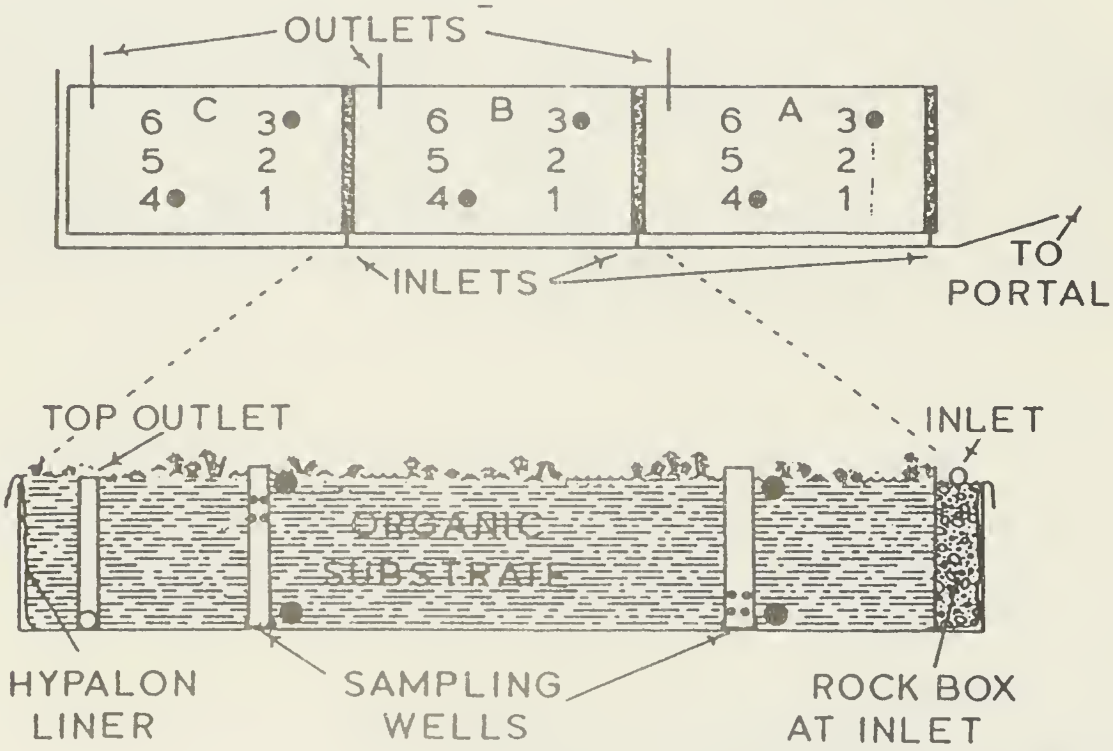

Figure 1. Initial configuration of the pilot treatment system.

The liner prevented chemical reactions between system components and mine drainage. PVC standpipes drained overflow water to a nearby pond. Baskets with 10-15 cm washed rock at the upstream end of each cell exposed a maximum cross-section of organic substrate to mine drainage. Six wells in each cell were perforated to sample interstitial water in surface, middle, and lower layers of the organic substrates. Insulated PVC lines fitted with ball valves controlled flow to each cell, and cells were filled to about 1 m deep with organic substrates. The first (Cell A) had mushroom compost, Cell B had equal parts of peat, aged manure, and decomposed wood shavings and sawdust, and Cell C had a 10-15 cm layer of 5-8 cm limestone rock beneath the same mixture as in Cell C. Cattails (_Typha latifolia_), sedges (_Carex utriculata_, _C. aquatilis_), and rushes (_Juncus arcticus_) from existing wetland sites in the region were transplanted into the cells (Howard, et al., 1988).

Samples of live leaves, dead leaves, flowers, roots, and organic substrates were collected and analyzed for metals concentrations before mine drainage was introduced into the system. Water sampling and analyses were initiated in October 1987. Samples were taken from the mine drainage, outputs from the three cells, and from the six access wells in each cell. Temperature, pH, Eh, conductivity, and dissolved oxygen content of the waters were measured in the field. Concentrations of Mn, Fe, Cu, and Zn and other trace metals were determined through atomic absorption analysis (Howard, et al., 1989a).

During the first year of operation, vegetation became established, with _Typha spp._ predominating over other species. Reduction in metal concentrations ranged from essentially none for manganese to nearly complete removal for copper. Reduction in concentrations of iron of up to 60 percent and for zinc of up to 100 percent were found (Table 1). Cell A was the most successful in removing some metals and increasing pH, but efficiency was greatly dependent on flow rates (Howard, et al., 1989b). The permeability of the substrates decreased with time, and flow was essentially short-circuited across the top of the cells. The initial design therefore did not provide sufficient contact between mine drainage and substrates to allow optimum performance of the system.

CELL A MODIFIED

Cell A was redesigned to enhance contact between mine drainage and substrates by increasing the length to width ratio and by attempting to introduce water into the subsurface with plywood partitions and distribution boxes (Figure 2). Mine drainage entered the first segment from an inlet box. Effluent was collected from the surface into a distribution box and delivered to the bottom of the next segment. This was repeated for a total of six segments. Level nylon lines were placed across each cell for measurement of water levels to determine the hydraulic head in any segment of the cell (Lemke, 1989).

A considerable amount of water flowed across the top of the cell segments and leaked from one segment to the others. An estimated 70 percent bypassed segments. Although the initial structure design was amenable to major changes, construction materials used in modifying Cell A were unable to maintain flow integrity, and substrate permeability remained too low to allow subsurface flow.

Table 1. Concentrations (mg/L) of metals and sulfate, percent reduction of metals, and pH in the Big Five mine drainage and cell output waters. Cell output flow rates are given in gallons/minute. The area of each cell is 18.6 m^2 (200 ft^2).

	Mn	% red.	Fe	% red.	Zn	% red.	Cu	% red.	SO_4^{2-}	pH	flow rate
December 11, 1987											
Mine Drainage	34		32		10.6		1.02		1750	2.8	
Output A	27	21	18	45	7.8	27	0.44	57	1560	4.6	1.0
Output B	33	1	24	26	9.8	8	0.89	12	1430	3.1	1.0
Output C	34	0	22	32	9.6	9	0.91	10	1520	3.3	1.0
February 13, 1988											
Mine Drainage	28		28		8.2		0.89		1750	3.3	
Output A	27	4	18	36	5.9	28	0.14	84	1690	4.7	1.0
Output B	31	0	28	0	7.6	7	0.92	0	1780	3.4	1.0
Output C	29	0	28	0	7.9	4	0.92	0	1700	3.4	1.0
May 31, 1988											
Mine Drainage	25		44		8.1		0.75		1500	3.0	
Output A	25	0	27	39	5.4	33	0.03	96	1330	4.3	1.0
Output B	25	0	17	61	7.4	9	0.64	15	1570	3.0	1.0
Output C	25	0	21	52	7.7	5	0.68	9	1220	3.0	1.0
August 19, 1988											
Mine Drainage	26		37		8.1		0.91		1460	2.9	
Output A	25	4	20	46	<0.1	100	0.17	81	650	5.5	0.51
Output B	26	0	15	59	6.1	24	0.55	40	<980	3.2	0.24
Output C	25	4	11	70	5.8	28	0.38	58	1920	3.5	0.34
December 18, 1988											
Mine Drainage	29		38		9.2		0.80		1710	3.0	
Output A	28	3	31	18	8.6	7	0.62	23	1710	3.4	1.21
Output B	28	3	30	21	7.8	15	0.74	8	1700	3.2	1.15
Output C	28	3	29	24	7.7	16	0.69	14	1710	3.3	1.25
February 21, 1989											
Mine Drainage	27		32		9.3		0.56		1860	3.0	
Output A	22	19	12	63	4.5	52	<0.01	100	1690	5.1	0.28
Output B	27	0	28	13	6.1	34	0.82	0	1880	3.4	0.31
Output C	25	7	31	3	7.2	23	0.26	53	2060	3.5	0.32

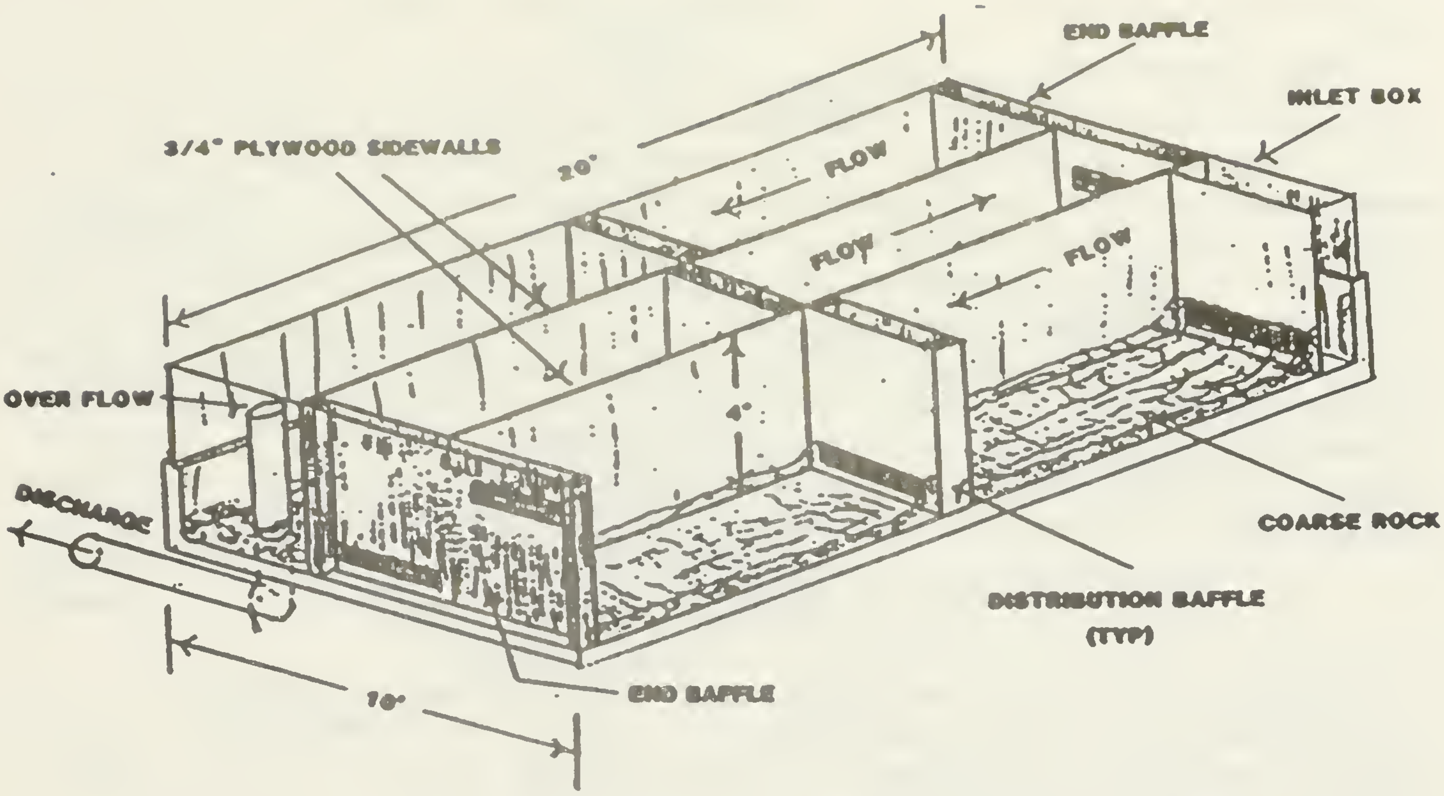

Figure 2. Cell A redesigned flow path (Gormley, 1988).

Permeability of the substrate is essential for efficient metals removal at optimal flow rates in long-term passive treatment operations. The loss of substrate permeability in an unacceptably short period of time was a continuing problem encountered during the operation of the pilot system. As permeability decreases, drainage is forced from the desired subsurface flow pattern to predominantly surface flow, and water passes over the substrate essentially untreated. Input flow rates must then be reduced or treatment area increased to maintain desired effluent quality. Substrate permeability must be maintained at an acceptable level throughout the 5 to 10-year targeted life if continuous passive treatment without maintenance or replacement is to succeed (Lemke, 1989).

Laboratory and intermediate-scale experiments were initiated to determine why substrate permeability decreases through constant exposure to mine water. Hydraulic conductivity, specific gravity, bulk density, size fraction, and dry weight of used and unused substrates were evaluated. No significant differences in these properties between used and unused substrates were found. Permeability tests were also performed including constant head downflow, falling head downflow, and upflow (Lemke, 1989).

Permeability enhancement was attempted through use of additives and removal of fine fractions. Four additives were tested for improving the uniformity and porosity of used substrate. Using equal volumes of substrate and additive, a goal of a thousandfold increase in permeability was chosen. Barley husks had no effect on the permeability of the substrate and promoted the growth of a white filamentous fungus. Angular 0.5 to 0.75 in. gravel was tested for both 1:1 and 1:2 mixtures of gravel to used substrate. Initial tests showed significant improvement in permeability, but after three trials permeability increased by about 80 percent and it appeared that gravel mixtures provided little improvement over unamended substrate. Perlite^R initially showed a tenfold increase in permeability, but the improvement was not sustained over repeated trials. Vermiculite^R gave an initial tenfold increase in permeability, and appeared to maintain that increase through repeated trials (Lemke, 1989).

Substrate additives did not provide the desired thousandfold increase in permeability. Amendments were chosen to augment the larger size fractions and improve size uniformity in the substrate. The proportion of fine fractions apparently remained large enough to fill voids. Permeability losses due to compaction, substrate swelling, and filling of void space due to the poorly sorted nature of the substrate were not eliminated by amending the substrate with barley husks, gravel or Perlite^R. The Vermiculite^R blend offered some improvement. Removal of fine fractions (<0.15 mm diam.) from used substrate was tested for improving permeability, but the improvement was shown to be primarily a result of using substrate that had been dried, recomposited, and rewet rather than a result of removing fine fractions (Lemke, 1989).

CELL B MODIFIED

Results of laboratory and intermediate-scale permeability experiments led to the modification of Cell B into upflow and downflow cells to monitor and evaluate permeability at the pilot scale. The original Cell B was divided into two lined, identical cells so individual variables could be tested (i.e. upflow vs. downflow, plants vs. no plants, etc.), and all parameters for calculating hydraulic conductivity would be available. The initial structure facilitated the change since extra drains had been provided. The plenum beneath each subcell was designed for even distribution of drainage in the upflow configuration and even collection when downflow is tested (Wildeman, 1989). The X-shaped, PVC distribution system was placed in the plenum below a supported wooden lattice. The lattice was covered with plastic construction fence and landscape fabric to exclude substrate from the plenum (Figure 3). Two feet of mushroom compost was used in both cells.

The precipitation of ferric hydroxides have been a problem in the operation of the pilot system by clogging inlet lines. Two 146 gal. stock tanks were added in series to pretreat the mine drainage before entering the upflow and downflow subcells. The tanks were added to prevent ferric hydroxides from accumulating in inlet plumbing where removal would be difficult, especially in the upflow configuration. The tanks also add two to four hours of retention time depending on inlet flow rates to the subcells.

Results from upflow tests gave permeability factors on the order of 10^{-2}, meeting the desired improvements in substrate permeability. The permeability factor could be increased or decreased through changes in flow rates. Downflow permeabilities were on the order of 10^{-3}. Upflow permeability will always be approximately 50 times greater than downflow systems with equal flow rates and upflow operating with negligible head loss. Table 2 shows preliminary water quality results for selected metals.

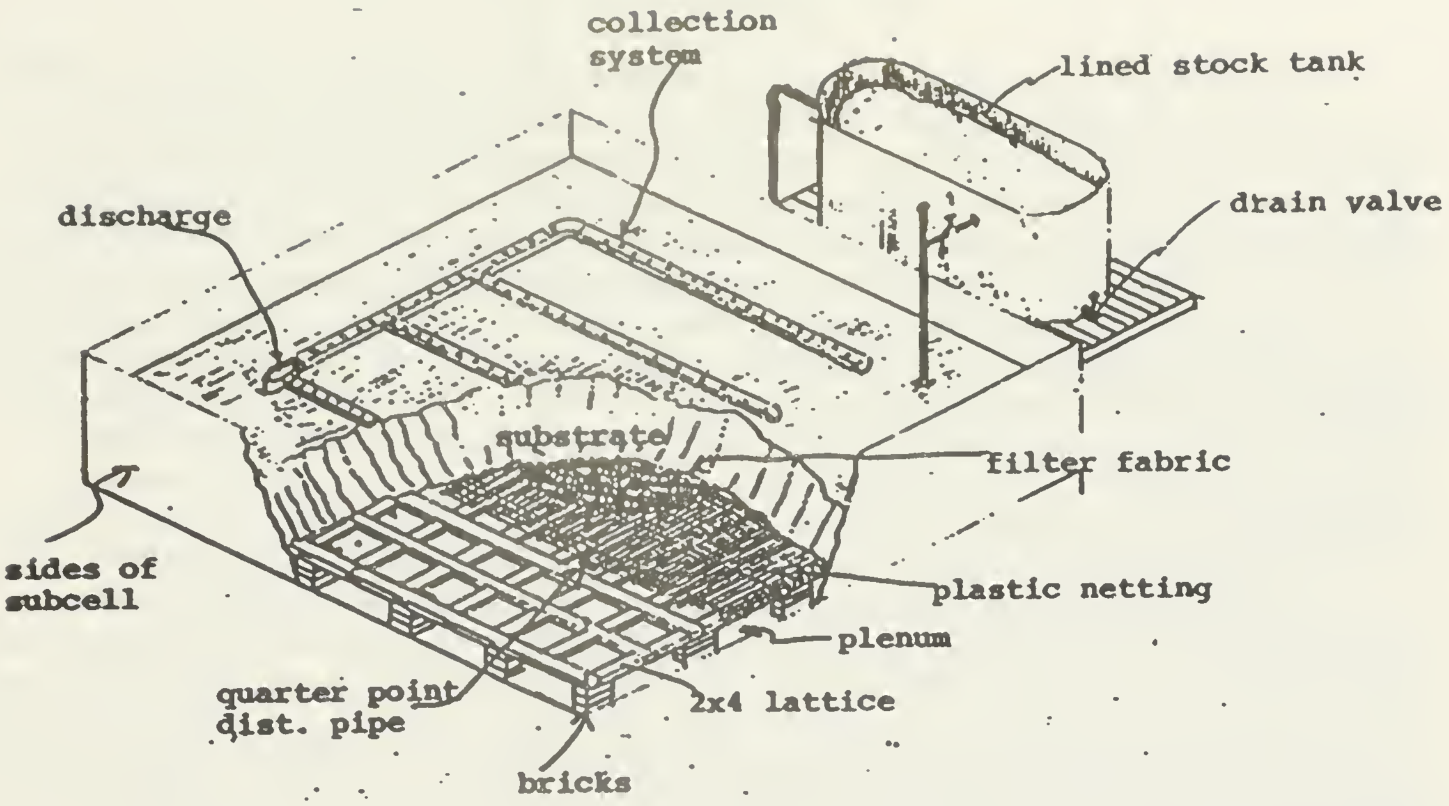

Figure 3. Design of upflow/downflow subcell (Gormley, 1989).

Table 2. Preliminary upflow vs. downflow results. Metals concentrations in ppm.

Parameter	Mine Drainage	Upflow Output	Downflow Output
flow rate	N/A	1.8 l/min	0.83 l/min
pH	2.9	3.3	6.4
Fe	37	18	0
Mn	30	27	6
Zn	8	8	3
Cu	0.6	0.4	0

Results indicated that the downflow system outperformed the upflow system in all measurements of metals removal and pH enhancement. It is important to emphasize the preliminary nature of these analyses, and the difference in flow rates to the subcells (Lemke, 1989). A strong inverse correlation of flow rate to metals removal efficiency has been observed in virtually all earlier work (Wildeman, undated). While the downflow appears more efficient at this point, both subcells should be operated longer at equal flow rates before definite conclusions can be drawn.

FATE OF METALS AND SULFUR

Metals removal is a critical goal of the treatment system. They may be transformed by microbes and precipitated as pyritic forms. Solid materials may be filtered by substrate and metals may be adsorbed onto substrate particles or complexed by organics arising from the substrate. Plants may take up substantial quantities of metals. Metals have been found to increase in the soils, and except for copper and iron, a few of the metals are in sulfide forms. Sequential extractions have shown that manganese and zinc are on reactive sites and are easily exchangeable. Silver and copper sulfides seem to be the most insoluble. Depending on the inflow rate, most metals are efficiently removed from the mine drainage except for manganese and zinc. Iron seems to be removed as oxyhydroxides (Cohen, et al., 1989).

Sulfur kinetics and dynamics have been studied through sulfur speciation analyses and geochemical modeling. The production and concentration of sulfide sulfur is of critical importance to the system. Metal sulfide mineral saturation indices are very sensitive to the amount of hydrogen sulfide in solution. High concentration of hydrogen sulfide promotes degassing of the system. Measurements of sulfides have been as high as 74 mg/L. Some of the sulfide may be in the form of CH^3SCH^3, although evidence suggests that most should be hydrogen sulfide. Several minerals are predicted by MINTEQ to precipitate and, in fact, do. Gypsum, a calcium sulfate mineral is obvious as a precipitate around plant roots (Cohen, et al., 1989).

Surface and subsurface substrates were sampled for sulfate-reducing and iron-and manganese-oxidizing bacteria. Sulfate reducers were found in numbers on the order of 300 X 10^6 and large numbers of iron oxidizers were also present. Large numbers of sulfate reducers such as _Desulfovibrio_ and _Desulfotomaculum_ suggest that sulfide levels initially used for geochemical modeling are artificially low. The relationships of the bacterial populations to many environmental variables have been examined. An important process in lowering the sulfate concentration of the Big Five Tunnel drainage is the reduction of sulfate to sulfide. This process occurs in the substrate of wetlands by sulfate-reducing bacteria. In this process, sulfur gases are generated including hydrogen sulfide, which, when lost to the atmosphere, contributes to the increase in pH of the system. Additionally, sulfide concentrations in the interstitial waters may play an important role in controlling the precipitation of metals in the system (Cohen, et al., 1989).

Metals were taken up in _Carex_ and _Typha_ leaves to levels of approximately 10,000 mg per kg of plant material. Iron and manganese were found in the largest amounts in the plants. There is evidence that the plants had saturated their uptake of Fe, Mg, Mn, Zn, and Cu (Cohen, et al., 1989).

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Wetland Development as a Portion of AML Reclamation

William L. Joseph [1]

ABSTRACT

The goal of AML reclamation is to development a multi-user land use that enhances the sites positive characteristics and eliminates negative ones. The AML program in the State of Kansas developed and reclaimed a large coal slurry disposal area by the use of wetlands. The main objective was to eliminate the acid mine drainage from the coal slurry and coarse coal refuse areas but at the same time retain the wildlife habitat that had naturally developed on site. Selective flooding of various areas by the use of a series of small dams was the selected reclamation option. The project is now completed and is working as planned.

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INTRODUCTION

The Kansas Department of Health and Environment (KDHE), Bureau of Environmental Quality, Surface Mining Section (SMS) Abandoned Mined Land (AML) program was contacted in May 1984 by the KDHE Water Quality Assessment Section (WQAS) which had been contacted by concerned parties regarding water quality problems of an unnamed tributary to Indian Creek. The Kansas Department of Health and Environment Water Quality Assessment Section initiated a Complaint Investigation/Assessment of the water quality problems of the unnamed tributary of Indian creek (KDHE-WQAS 1985).

The study determined that acid mine drainage was being generated in the head waters of the unnamed tributary in Kansas and Missouri. The acid water was being generated by coarse coal refuse from an old tipple in Missouri and coal slurry and coarse coal refuse in Kansas. The water quality problems in Missouri should have been corrected by the MO-AML Sawmill project. This AML project did not correct the water quality problems and runoff from Missouri was still acid (2.3 pH) and contained high levels of heavy metals.

The SMS AML program dedicated monies in 1987 to study and develop reclamation options for the Indian Creek pollution problem. In 1988 the Kansas AML program chose the preferred reclamation of the Indian Creek Site and began construction in the summer of 1989.

WATER QUALITY INVESTIGATION

The Water Quality Section conducted an investigation in 1984 to document the water quality and aquatic life of the unnamed tributary and the confluence with Indian Creek. The investigation documented algal, macroinvertebrates and fish communities in comparison to the communities that should have been found. The algal study concluded that the unnamed tributaries pollution had effected Indian Creek at least one mile below the confluence. The watershed of the unnamed tributary had developed runoff that was low in pH and high in heavy metals. The macroinvertebrates where also impacted based on the number of species found and the diversity. The iron coating of the tributary bottom was stressing and eliminating the algal community which in turn controlled the macroinvertebrate populations dependent on the algal communities. There were no fish found in the unnamed tributary were fish should have been. Fish populations were present above the confluence of the unnamed tributary but not below.

In conclusion the investigation found that the acid mine drainage was causing significant acid and heavy metal loading of the unnamed tributary and also effecting portions of Indian Creek. The algal community and benthos of the unnamed tributary decreased as the pollution problems increased up the tributary. The pollution was being caused by the oxidation of iron sulfide minerals in the watershed and an acid pond in Missouri.

SITE INVESTIGATION AND RECLAMATION ALTERNATIVES

The SMS utilized the initial water quality investigation and the priority one AML problems on site to justify the allocation of monies to investigate the sources of the pollution problems and to develop reclamation alternatives. The site consists of a 640 acre area of mine dumps with many final pits. The coarse coal refuse covered approximately 30 acres of the upper watershed area. The final cuts had all been filled in with coal slurry which covered approximately 70 acres. The coal slurry and coarse coal refuse areas were sampled in early 1987 to find out there acid generation ability.

The site was inventoried for all reclamation needs. The acid water being generated in the portion of the watershed which had already been reclaimed by the MO-AML program could not be corrected by further AML work in MO. The acid water running into Kansas would be a continual source which would require treatment. The acid water ran from MO in a defined channel aground a large dam and then into the coal slurry areas and eventually to the unnamed tributary.

A lake which had been built by the coal company for a water source had a breach in the dam and which acted as a fresh water source to the MO acid water which buffered the pH and dropped the Iron out. The breach in the dam was a safety hazard which had to be corrected. The concept of a mixing pool that would take the acid water from the Mo tributary and the water from the lake was developed from this breach. This would be similar to what had been occurring on the site and was improving the water quality but not correcting it.

The majority of the slurry had no vegetative cover and was acid. Several small areas had developed into wetlands naturally when the steep sided spoil banks had failed and developed small dams on the slurry. These areas had stable plant communities and neutral pH levels in the water and the slurry surface. The main reclamation option decided to follow up on was the development of several small dams throughout the slurry system to create a series of wetlands. This would reclaim the surface areas of the slurry and work as a cleansing system for the acid water coming from MO.

The SMS selected an engineering firm to design the project. The engineering firm was given several conceptual design ideas. The conventional idea was to grade all the spoil areas over the coal slurry and coarse refuse and revegetate the area for pasture use. The preferred concept was the development of a series of wetlands. The engineering firm had been informed by the SMS of the work being done by Southern Illinois University Cooperative Wildlife Research Laboratory. They have been the leaders in the area of slurry reclamation by the use of wetlands. The engineering firm utilized staff of the SIU-CWRL to design the conceptual and final plans. The pre design work included the SMS staff making several trips to reclamation symposiums and to the work being conducted by SIU to see if the reclamation option of wetlands would work in Kansas. The success seen in Illinois gave us confidence that Indian Creek would be an ideal location to build a series of wetlands.

DESIGN

The engineering firm developed several options for various sized wetland cells. The engineering constraints were outlined in several meetings with the SMS. The engineering firm designed the dams for each of the wetland cells to hold 80 percent of a probable 6 hour storm as per MSHA requirements for structures which impound coal refuse. This made the cost of each structure much higher than originally anticipated. The number of dams had to be reduced in order to keep the project within the AML program budget constraints. The final design chosen was the construction of five small dams. The water depth behind each structure ranged from 4 feet to several inches. The larger dam size would decrease some shallow water areas behind the dams on the slurry but would create more shallow water areas in the fingers of the spoil ridges.

The coarse coal refuse on site was to be buried but no disturbance of the oxidized surface was to occur. The surface of the slurry and the coarse coal refuse were well oxidized with little potential acidity. The disturbance of this surface would have resulted in exposing high potential acidity materials.

The dam of the lake was to be reconstructed with two spillways which would seep into different portions of the wetland system. The seeps would insure a continual fresh water source into the wetland system other than the run off from MO.

CONSTRUCTION

The course coal refuse was first limed with 75 tons of 100% Effective Calcium Carbonate (ECC) per acre. The area was then covered first by filling in the gullies and depressions with adjacent spoil and then finally covering the area with at least two foot of spoil. This method of grading prevented the disturbance of the coarse refuse oxidized surface. The trees from the spoil borrow areas were stacked in piles throughout the coarse refuse area for wildlife cover. The seedbed was prepared by a rome disk with a minimum penetration of nine inches into the surface. This created an ideal seedbed for the vegetation. The area was then seeded with native grasses and then mulched with seed laden native grass hay.

The dam of the lake was reconstructed with the two principal spillways and seep pipes. The slurry was then limed at 70 tons of 100% ECC per acre. The slurry surface was very unstable which made the liming procedure interesting. The contractor built small roads from the spoil banks down to the slurry. Then they used a large lime truck to shoot the lime out over the surface of the slurry. The slurry surface in some area was solid enough to be directly limed.

The five small dams were then constructed on the slurry surface. The slurry at the dam location was first covered with a geotextile fabric. This fabric allowed the contractor to utilize large equipment on the surface of the slurry. The geotextile fabric was covered by adjacent spoil and then compacted with a sheepsfoot roller in a series of lifts. The dam surface was then covered with gabion baskets filled with limestone. The water can flow over the entire length of the dams through and over the gabion baskets. The lake dam and the disturbance caused by the small dam construction was disced to nine inches limed fertilized and seeded with cool season grasses. The entire slurry surface was then seeded by hand with japanese millet.

RESULTS

The project was completed in the fall of 1989. The wetland cells have all attained there design water levels and the site is now discharging into the unnamed tributary. Initial water sampling of the site discharge into the unnamed tributary has shown neutral pH levels and negligible heavy metal levels. The wetland plants are beginning to invade the various wetland cells. The mixing pool is working well in raising the pH level but has not removed all the metals. The cells will be planted this spring and fall of 1990 with cattails, bullrushes, sedges and phragmites as part of the maintenance contract on the area. The water quality of the site will be monitored continually during the two year maintenance period. The project has been successful in eliminating the iron coating and acid water problems of the unnamed tributary. We expect the water quality to remain good as the wetland cells develop. The use of wetlands to reclaim AML problems is a cost effective and environmentally sound method of reclamation.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

EVALUATION OF A DRASTICALLY DISTURBED SITE AT LAKE TAHOE TEN YEARS AFTER RESTORATION

William N. Johnson

ABSTRACT

In an effort to curb the adverse impacts of urbanization on the quality of Lake Tahoe, wetlands are being restored and used to treat polluted runoff before it enters the Lake. One such project involved the purchase of a 20 acre site with a partially constructed hotel casino referred to as the Jennings Casino Site. Restoration of the site included the reconstruction of a section of Burke Creek, (a 3290 acre heavily developed watershed on the East shore of Lake Tahoe), construction of a sediment pond, and recreation of a wetland. Water quality data collected between 1982 and 1989 showed significant improvements to water quality for the entire drainage as it passed through the sediment pond and restored wetlands. A decrease in treatment levels by the wetland has stimulated a new look at the project to set up a management program for the wetland.

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INTRODUCTION

Extensive urban development and associated road construction at Lake Tahoe yield significant quantities of nutrients, sediment and other pollutants. Further development in wetlands, riparian areas and stream environment zones has resulted in the channeling of these pollutants directly into the lake, resulting in decreased clarity and algal growth. During the past 15 years a major effort has taken place in the Lake Tahoe Basin, aimed at restoring disturbed areas. A significant portion of this program has centered around the restoration of wetlands, riparian areas and stream environment zones. The objective of the program has been to take advantage of the natural treatment provided by these systems. One such example is the Jennings Restoration project. This paper evaluates the effectiveness of the project for treating polluted urban runoff over the past 10 years.

Project Description

The Jennings site is located on the East Shore of Lake Tahoe on the lower reaches of the Burke Creek adjacent to Lake Tahoe. Burke Creek is a 3,290 acre watershed, draining a heavily developed area on the Nevada side of Lake Tahoe. The 20 acre parcel was purchased by the U.S. Forest Service in 1980. Approximately 18 acres of the 20 acre parcel had been drastically disturbed as a part of an initial construction of a 23 story hotel/casino. A major wetland was destroyed and Burke Creek was piped under a portion of the parcel and carried to Lake Tahoe via a concrete channel and earth channel for approximately 1 mile. The construction site was graded flat and all topsoil was removed. 1.5 million dollars worth of concrete had already been poured in the form of 127 supports extending 30 feet into the ground to support the hotel.

As a part of the initial restoration the concrete was removed from certain areas and the site was reshaped to approximate the natural conditions that once existed. A new channel was constructed for Burke Creek with a meander pattern similar to that of the original one. A large sediment pond was also excavated at the lower end of the parcel. Burke Creek was routed through the pond, then into the meadow where it once flowed. The new stream channel was lined with a layer of filter cloth, then by 1-1/2 inch minus gravel and finally a layer of 6 to 12 inch cobbles. On the low gradient sections filter cloth was not utilized.

Revegetation began in 1980 by ripping the reshaped site to a depth of 12 inches for seedbed preparation. The site was seeded with a variety of seed mixtures, fertilized and mulched with straw. Slopes in excess of 30 percent were then covered with jute matting. The site was irrigated during the first season of growth.

Approximately 3,000 containerized shrubs and trees in one, two and five gallon container sizes were planted. A detailed description of the species planted and survival rates can be found in "High Altitude Revegetation at Lake Tahoe" (Johnson 1985).

Water Quality Monitoring Program

To determine the effectiveness of the wetland and sediment pond for removing pollutants, four water quality monitoring stations were set up. Samples were collected from Burke Creek above the project, below the sediment pond, from a spring feeding Burke Creek, and below the meadow. The following parameters were monitored: Discharge, temperature, total nitrogen, total phosphorus, dissolved phosphorus, suspended sediment, turbidity, alkalinity, conductivity, total hardness, fecal coliform, dissolved oxygen and pH. Samples were analyzed in the Forest Service lab at South Lake Tahoe. Data was collected from 1981 to the present, with the exception of the 1986 and 1987 water years (Holland 1982-85). Approximately 17 samples per water year were analyzed from each station.

Monitoring Results

For the purpose of this study, the data was evaluated to determine the effectiveness of the meadow and the sediment pond as separate treatment systems. Parameters evaluated include: suspended sediment, total nitrogen, total phosphorus, and dissolved phosphorus. All values are the mean of the total number of samples collected for the indicated water year. Removal of these parameters are most critical to the protection of Lake Tahoe. This project provided an excellent opportunity to evaluate the effectiveness of the various restoration techniques.

Sediment Pond

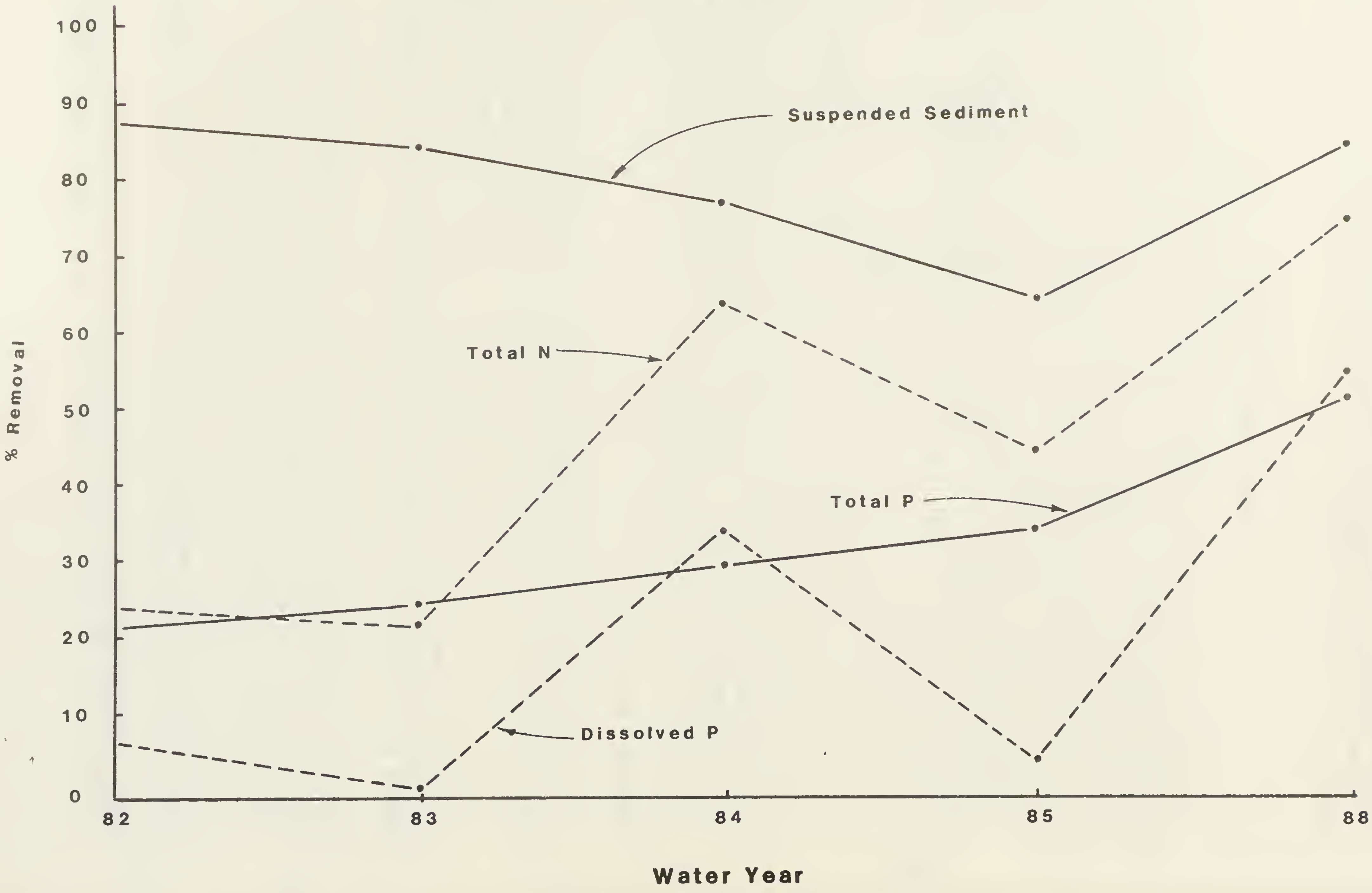
Graph No. 1 shows the mean percent removal of the four parameters by water year. The 89 water year data was not available in time for this publication. Most striking is the removal of suspended sediment which ranges from 67 to 89 percent removal for the total watershed. Total nitrogen removal is also high, ranging from 24 to 75 percent. Total phosphorus removal comes in a close third with 21 to 53 percent total removal. The data for removal of dissolved phosphorus is variable over the years monitored ranging from 0 to 57 percent.

The graph line for total nitrogen and dissolved phosphorus removal are similar, indicating possible vegetative removal. Increased removal in later years may also indicate increased vegetative activity as algal growth continued and the wetland vegetation around the pond developed. Approximately .5 miles of new stream channel carries flow from the upper monitoring station to the pond. The riparian vegetation along this stretch is now heavily developed and may also be contributing to the increased removal of these two nutrients.

The graph line for suspended sediment and total phosphorous are also similar. Their removal would primarily be by settling. The high levels of

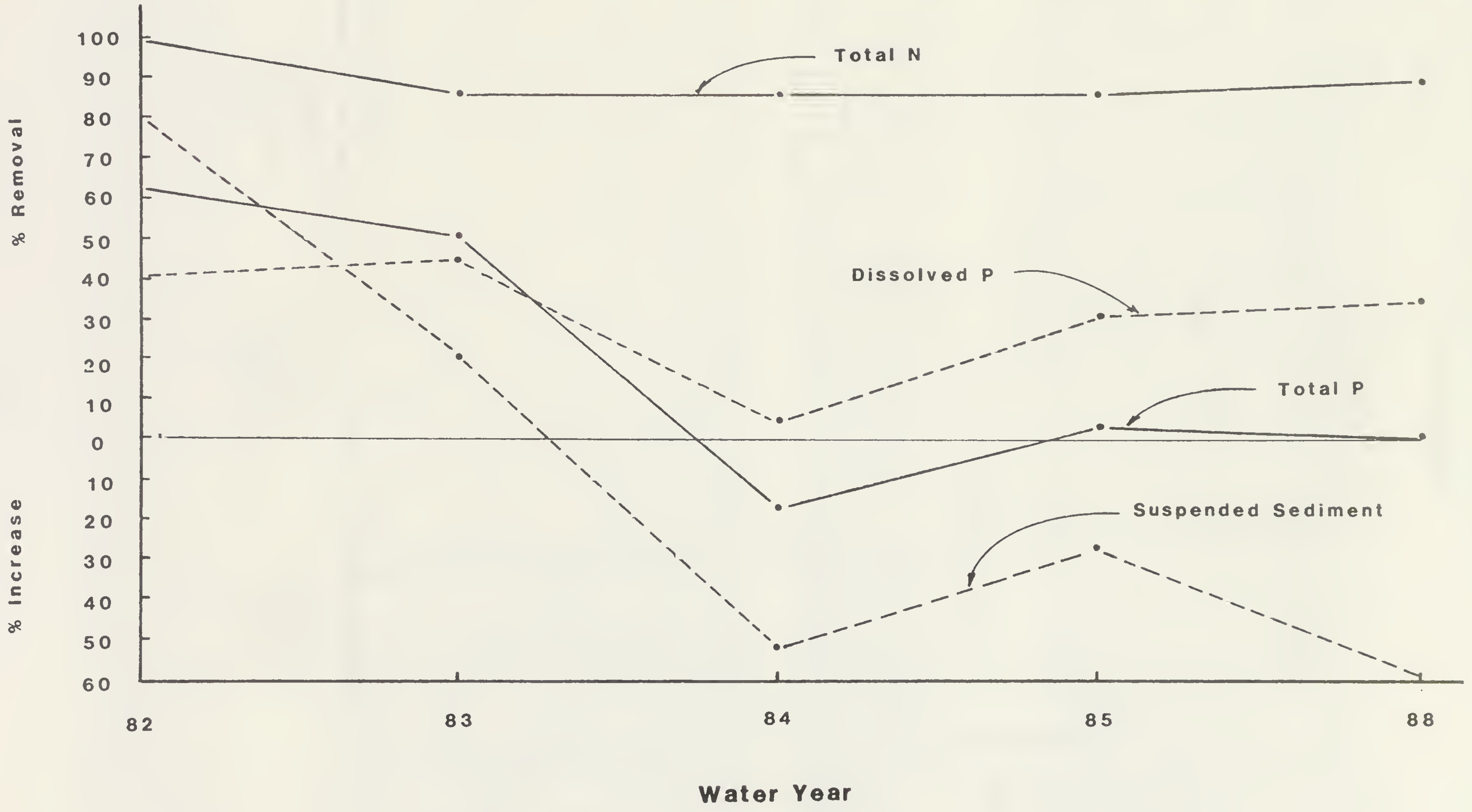
Graph No. 1

Removal of Sediment and Nutrients By Sediment Pond



Graph No. 2

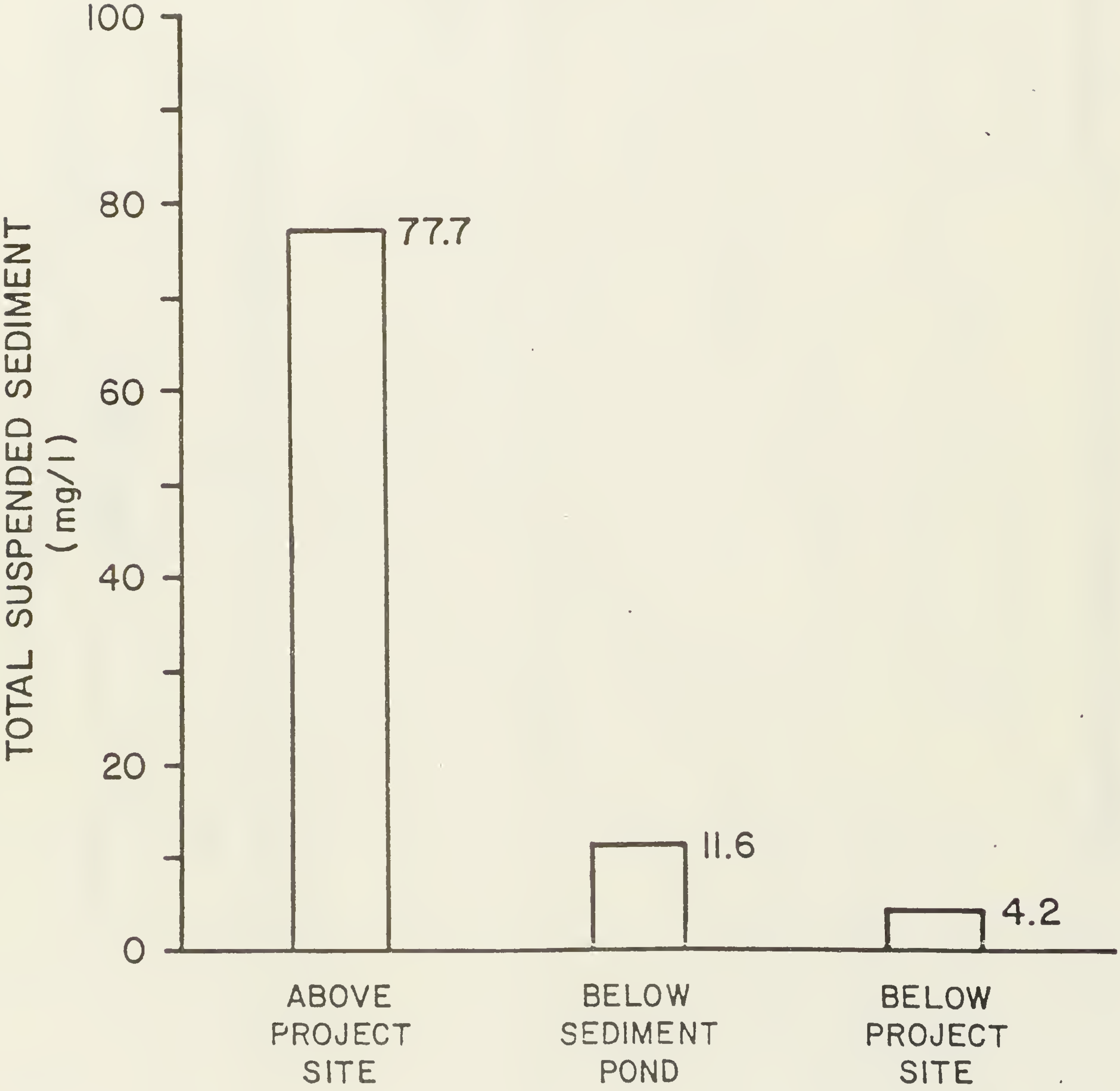
Removal of Sediment and Nutrients By Wetland Treatment



Graph No. 3

JENNINGS
REHABILITATION PROJECT

1982 WATER YEAR



removal of these nutrients indicates the sediment pond is still functioning quite well.

Wetland Treatment

The most striking treatment taking place in the wetland is the removal of total nitrogen, which ranges from 88 to 97 percent total removal for the entire watershed. Dissolved phosphorus showed decreases but not as great, ranging from 5 to 47 percent removal. The majority of this removal is probably by vegetative uptake. What is striking is the decrease in treatment of suspended sediment and total phosphorous since the project was completed. Total phosphorous treatment, the first year after diverting the creek back into the meadow, was 62.4 percent. By water year 1988, treatment had dropped to 0 percent with a 15.8 percent increase in water year 1984. Suspended sediment treatment dropped from 82 percent removal in 1982 to an increase of 62 percent in the 1988 water year. These percentages represent the mean of all samples for the year. In looking at individual measurements during high flow periods the removal of suspended sediment ranges from 24 to 56 percent and nitrogen from 82 to 89 percent.

Conclusion

The sediment pond was originally designed for a life of 10 years. It was anticipated that this would be adequate time for the agencies to implement mitigation measures to resolve the problems at their source. The pond is still functioning well, as is evidenced by the high level of suspended sediment removal, and will probably have an extended life due to the series of low runoff years brought about by the drought in the Lake Tahoe area.

Treatment of runoff flowing through the meadow was exceptional for all parameters the first year of diversion. By the second year the level of treatment for all parameters was greatly reduced. In evaluating the cause for the reduced treatment over the years, several possible reasons exist. First, the runoff was directed in a straight shot through the meadow which caused some channeling and head cutting, which has increased over the years. This could result in the channeling of pollutants through the meadow, reducing over bank flows, explaining the overall increase in sediment production during the 84-88 water years. This is evidenced by the fact that removal of suspended sediment and total nitrogen still occurs during high flows that exceed the channel capacity. This is important, since during major storm and runoff events as much as 80 percent of the yearly sediment and nutrient load may occur. Second, is a loss of percent vegetative cover that appears to be a result of the constant growth and dieback of vegetation. This situation is hampering the regrowth of riparian vegetation. Both of these problems could easily be resolved by setting up a management program for the wetland.

Recommendations

Long term water quality data collected on this project shows that wetlands and sediment ponds can effectively remove large quantities of suspended sediment and nutrients. The use of sediment ponds and wetlands for treatment of urban runoff should not, however, be considered the total solution to the problem. It is essential that appropriate mitigation measures be implemented at the source of the problem regardless of its nature. Erosion control ordinances that address both temporary and permanent site stabilization are necessary. Programs also need to be developed to provide incentives to control erosion from existing problem areas.

Without proper management, wetlands will loose their capability to treat pollutants. Visual and or water quality monitoring programs should be set up to identify potential problems. Capacities for treatment need to be determined for wetlands before pollutants are indiscriminately dumped into them. In addition to stabilization of upstream development, the infiltration of runoff should also be considered to provide further treatment, reducing the impact of high flows on wetlands and the associated channel systems.

A plan is currently being developed to meander Burke Creek through the meadow to lower velocities, and increase overland flow and detention time. Loose rock check dams will be constructed in the down cut channel and willows will be planted for bank stabilization. A vegetation management program will also be necessary to address the decrease in percent live vegetative cover. Such practices as spot grazing, burning or haying may be necessary.

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Planning, Rehabilitation and Treatment of Disturbed Lands
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NEW RECLAMATION TECHNOLOGY FROM A CONTRACTORS POINT OF VIEW WHAT WORKS-WHAT'S QUESTIONABLE

David Chenoweth

ABSTRACT

Reclamation contractors often times utilize new erosion control/revegetation products which may help achieve successful revegetation. Also, some contractors have the ingenuity to fabricate or modify reclamation machinery to meet specific job requirements. The products or techniques which Western States Reclamation has experimented with include water absorbing polymers, humic acid soil amendments, new types of erosion blankets, and wetlands plantings to reconstruct riparian zones. Some of these revegetation techniques show obvious visual signs of helping to achieve revegetation success, while others are questionable. Western States Reclamation hopes to spark the interest of those individuals or agencies who are better able to fund and spend time researching those techniques which they feel show potential for revegetation success.

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INTRODUCTION

After spending five years in the coal mining industry as an Environmental Coordinator, and then starting a revegetation contracting business, I noticed one major difference--limited budgets to conduct research on ideas which may lead to successful revegetation techniques. At the time I worked for industry, it seemed we had a perpetual tidal wave of windfall profits to back our desires for more reclamation research and new machinery. However, as we reached the early 80's, even large energy companies tightened their belts because of the economic slump, and research budgets were more controlled.

As a contractor, I have found it frustrating at times to find the money and time to go back and quantitatively determine which techniques work, which do not, and which are still questionable. Therefore, the purpose of my paper is to inform you of what Western States Reclamation has experienced over the past several years in terms of new reclamation technology. Also, as I identify the techniques we feel work versus what is questionable, I hopefully will spark an interest in those individuals who have the time, funding and expertise to evaluate and inform those of us who need to know. The topics I have chosen to speak about are new types of reclamation machinery, polymers, wetlands plantings, soil amendments, mulches/tackifiers, and erosion netting.

RECLAMATION MACHINERY

THe 1980's brought us four-wheel drive farm tractors which made it much easier to work steeper slopes while staying on the contour. The major manufacturers of revegetation type drill seeders took our advice and made their product stronger and with better agitation devices. The problem I see is that we are like cowboys in a rodeo on our new four wheel drive tractors but our implements can not always keep up with us. For example, drill seeding on a steep slope does very little good when a tractor is swaying from side to side on unstable materials. Also, without adequate dividers in the seed box, all of the seed slides to the low end of the drill resulting in a three to five foot planting width with an eight foot drill. This may sound exaggerated, but I actually saw a mine site where another contractor had drill seeded a 2:5:1 slope and it resulted in meander drill patterns approximately three feet wide across the slope. On this project, the client would have been better off allowing the contractor to either use broadcast seeding or hydroseeding. However, the key to successful broadcast seeding or hydroseeding is follow up by lightly harrowing, raking, or slope chaining the seed into the soil.

There still appears to be a major gap in the market availabilty of drill seeding and broadcast seeding equipment which will handle shrub species. Also, our ability to seed shrub and grass species simultaneously is very difficult. Obviously, shrub and grass seed have significantly different sizes, textures, and planting depth requirements.

Last year, we completed a project in the Powder River Basin which required seeding grasses and shrubs on the same area. Our objective was to complete these two tasks in one pass across the reclaimed area to avoid compaction and cut unnecessary man hours. To accomplish this task, we utilized an electric broadcast seeder mounted on the front of a tractor to seed the shrubs, followed by a drill to seed grasses. The drag chains behind the drill were perfect for covering the shrub seed with soil. At first, we had significant problems with shrub seed bridging in the broadcaster. This problem was partially overcome by mixing the shrub seed with rice hulls and adding a wire agitator inside the broadcaster. We also equipped the broadcaster with a rheostat for speed control and a throttle cable to close and open the gate at the bottom of the spreader. It would be nice to see someone design a broadcast spreader which avoids bridging of fluffy/trashy seed, or can properly agitate the seed, if it has not been done already.

There are currently several different straw/hay mulches on the market. Machines which handle large bales are popular for large projects with relatively flat slopes. However, within the realm of big bale machines, some are extremely top heavy and pulverize mulch to the point that the fiber length is too short for adequate crimping. The straw cannon type machine still seems to be the best and possibly only alternative for mulching on extremely steep slopes.

WATER ABSORBING POLYMERS

Polymers are crystals or powder which are able to absorb up to 800 to 1,000 times their weight in water. This product is being used more in seeding operations and tree/shrub plantings. There are two dominant types of polymers--starch based and inorganic compounds. Starch based polymers absorb the greatest amount of water, but inorganic polymers have the greatest life expectancy. I feel there is potential benefit from the use of polymers, but a lot of questions as to what conditions they work best.

During the Fall of 1986 and Spring of 1987, our company revegetated an abandoned mine near Steamboat Springs for the Colorado Mined Land Reclamation Division. The specifications on this project called for treating the seed with a powder type polymer. We accomplished this task by first spraying the seed with an agricultural adhesive called Rhoplex, and then polymer was sprinkled over seed. By using a microscope, we were able to confirm that the polymer had adhered to the seed.

Colorado Mined Land Reclamation Division conducted quantitative studies on areas seeded with the addition of polymer. These studies were completed approximately six months and one year after seeding. The indications were that there was no significant difference in vegetation establishment or production on fall or spring planting. The lack of benefit from the polymer could have been due to the fact that the project area receives enough precipitation to allow grasses to germinate and fill in when compared to more arid areas of Colorado or surrounding states. Also, two tons per acre of hay mulch was applied to all seeded areas which enhanced moisture retention and may have lessened the need for the polymer.

On another project our company seeded during last Fall (1989), HYROSOURCE POLYMER which is a larger crystal than the HYDROGEL we used at Steamboat Springs, was mixed in the drill hopper with the native seed mix and planted at a rate of twenty pounds per acre. This product seemed to help germinate the grasses sooner, but the long term benefit of the product remains to be seen.

During the Spring of 1989, we used HYDROSOURCE POLYMER in the soil backfill of bare shrub plantings on a Colorado Department of Highway revegetation project near Vail. Several of the bare root plants were dug up the following October (Fall 1989) and significantly more soil moisture seemed to be in the root zone of the plants than in surrounding soil. Also, a density count of the bare root plants indicated up to 80% survival rate.

The questions I have in using polymers in both seeding and plantings are as follows:

1) Under what precipitation patterns do polymers work best, if at all?

2) Do the finer powders or larger crystals work better on seeded areas? Also, do the larger crystals have to be fully hydrated before they release moisture to seedlings?

3) As the roots of grasses and plants extend deeper in the soil, do polymers confine release of moisture to the shallower areas where they were originally placed, thus becoming detrimental to plant growth over time?

4) If polymers really work, can they offset the need for mulch on areas where relatively flat areas exist and surface erosion is not a concern?

WETLANDS PLANTINGS/BIOENGINEERING

Significant work is being performed in the field of wetlands replacement. This work consists of utilizing plant cuttings, seed, and sprigs of various vegetation to establish wetlands/riparian areas which enhances wildlife and fisheries habitat, as well as protecting stream channels from erosion.

Some of the work our company has completed in this area includes brush layer cuttings and tuber plantings. On a Colorado Department of Highway project located near Fairplay, Colorado completed during the Spring of 1989, we had significant success in re-establishing willow communities by utilizing brush layer cuttings. The cuttings were taken in a dormant stage from nearby stands of sandbar willow and were cut an average of 24 inches long. The top end of the cutting was represented by a blunt cut, while the end to be placed in the soil was cut at an angle to provide a larger surface area for reformation of roots. Care was exercised in rejecting diseased material. The cuttings were soaked in the adjacent stream for at least 24 hours to callous the root end. A pry or rock bar was used to form a hole in the streambank followed by inserting the cutting into the hole. The brush layer cuttings were watered daily for a period of two weeks. After this period of time, some of the cuttings were pulled from the streambank to confirm that new roots were forming, which was the case.

The project engineer was extremely pleased with the success of the earlier brush layer cuttings. Therefore, he asked that we install an additional 6,000 brush layer cuttings in a nearby peat bog that had been used as a borrow pit. We cautioned him about our concerns over much lower potential success ratios due to leaf out of willows since we had completed the first series of cuttings. To help offset this concern, willow cuttings were again soaked in a nearby stream and then dipped in a hormone solution to help initiate root reformation. To our surprise, we again had an extremely high success ratio with the cuttings. The average cost was $1.50 for each cutting which is considerably cheaper than buying and installing nursery propagated material.

For a Colorado front range project completed on a detention pond, the scope of work called for replacement of cattails on the pond's permanently wetted perimeter. This task was completed by obtaining root sections of cattails from a pond approximately 60 miles away. The cattail root sections were placed in soil or muck material which we felt would always remain permanently wetted. The results of our efforts proved a 90% success rate. That fall, we also placed cattail heads in the wetted soil in hopes that once the seedhead ruptured, we would obtain cattails from propagation of seed the following spring. Again, this endeavor seemed to be very successful. At this point, it appears very difficult not to get a stand of cattails if any concerted effort is made at all in planting operations.

I am aware of numerous other projects that have been completed in Colorado and surrounding states with a high degree of success using collected stock, cuttings, and nursery propagated material. The key to success is planting in hydric type soils, careful selection of plants adapted to the site and free of disease, and supplemental watering as needed until adequate root establishment is accomplished.

SOIL AMENDMENTS AND FERTILIZERS

For the purposes of this discussion, I consider soil amendments as organic materials and fertilizers as inorganic materials. Two organic fertilizers which we have been experimenting with are Humagro and Biosol. Humagro is a humic acid based material which appears to help in re-establishing soil structure of disturbed soils or newly topsoilled areas. Essentially, Humagro helps form soil particles into aggregates which enhances water and air exchange in the soil profile. Biosol is an organic soil fertilizer derived from food substances utilized to manufacture penicillin. It provides valuable organic matter/humic acid to the soil. Also, it contains valuable micro and macro nutrients released over time to plant materials and is advertised by its manufacturers to help re-establish a substrate for soil microorganism populations.

The experimentation we have done with Biosol can not be interpreted at this time since applications were completed in late summer and early fall. However, literature and testimony by other sources are quite impressive and indicate Biosol enhances vegetation cover and diversity on areas void of organic matter/humic acid which is critical to successful revegetation effforts.

Humagro was tested on a gravel quarry near the front range of Colorado which proved difficult in the past to achieve adequate revegetation. This product which has the appearance of coal dust was mixed with seed in a hydroseeder and applied at a rate of 650 lbs. per acre. The area where Humagro was applied consisted of interseeding an area which had been previously seeded, but showed poor results. Our only ability to assess the use of Humagro to date, consists of visually comparing the interseed area to those areas not interseeded. It appeared that a significant increase in vegetative cover was accomplished by interseeding and use of Humagro. Since the seedbed material contained very little, if any, topsoil, I feel that Humagro played a significant role in increasing vegetative cover.

Commercial fertilizers consisting of mixtures of nitrogren, phosphorus, and potassium are often times applied at the time of seeding. Research conducted by Thunder Basin Coal Company indicates that if nitrogen is installed at the time of seeding, it may increase weed invasion during drier years, and potentially cause significant competition with desired species. According to published documents on principles of range management, researchers feel that nitrogen can not be utilized in seedling plants until there is sufficient leaf area to uptake and utilize this nutrient through leaf tissue. However, weed species can readily utilize nitrogen for increased growth. Therefore, the question becomes is it better and more cost effective to apply nitrogen fertilizer approximately one year after seeding and germination of desired species? Or, can legumes be utilized in sufficient quantities to offset the need for applying commercial nitrogen products?

MULCHES

I consider there to be two different types of mulches. They are hay/straw mulch and hydraulic mulches. The difference that exists between hay and straw mulch is hay can provide volunteer seed source and covers better than straw when comparing the same application rate. On the other hand, straw mulch helps prevent competition from undesirable seed found in some types of hay mulch. One of the major problems with utilizing straw mulch is its fiber length. Apparently, the new style rotary combines cut the wheat stubble into shorter fiber length than older style combines and it is baled accordingly.

Hydromulches have been around for the last 25 to 30 years. A true virgin wood cellulose fiber mulch will provide a blotter action on the soil surface after it is applied. This allows the individual fibers to interlock and become more difficult to wash away from rainfall. Over the past several years, new hydraulic mulches have entered the market and they are advertised as being cheaper and as effective in controlling erosion as their predecessors. These new mulches often times resemble sawdust and will not retain blotter action like a true virgin wood cellulose mulch. Thus, the less expensive sawdust type mulches break down or wash away much quicker than the virgin wood cellulose mulches.

Tackifiers have become more prominent in use with hydraulic mulches and as an overspray for hay or straw mulch. There are two major types of tackifiers. They are starch based and seaweed derivatives. Western States prefers using a combination tackifier hydromulch as an overspray on hay or straw mulch where steep slopes prohibit efficient crimping operations. The ratios of materials that we like to use are 100 lbs. of tackifier to 200 lbs. of hydromulch and 800-900 gallons of water. If too little water is mixed in the slurry, the mixture will not flow between the mulch and the soil, whereas, if too much water is put in the slurry, it reduces the gluing affect of the tackifier.

During 1988 we were faced with revegetating a 1:1 slope on unstable soils. We felt the only way to seed the area was by utilizing a hydroseeder but we were afraid that if we applied the seed and the mulch in two different steps, it would result in slumping of the soil and loss of seed. Therefore, we tried what we later called a heavy glue application which consisted of using 250 lbs. of tackifier per acre, 150 lbs. of hydromulch per acre, and 900 gallons of water per acre. This technique allowed us to plaster the seed to the slope without causing slumping of the soil. While the results of this technique provided a limited number of seedlings per square foot after germination, the client still felt the technique was better than previous attempts to revegetate this area.

EROSION CONTROL BLANKETS

Numerous soil erosion control blankets are available on the market today. They include blankets made of excelsior matting, jute netting, straw mats, and coconut mats. Excelsior blankets were introduced in the early 1960's, while jute netting was introduced in the early 1950's. The straw and coconut blankets came into existence in the United States in the early 1980's.

Manufacturers' recommendations for the erosion blankets are normally based on the steepness of the slope or velocity of flow in the drainageway. For moderate slopes or low flow drainage channels, we have found that excelsior blanket or polypropylene netting placed over hay or straw is adequate to help control erosion. As the degree of the slope increases, or the velocity of the channel's flow increases, it becomes necessary to utilize blankets which are heavier/thicker and contain netting on both sides of the blanket. Those materials which fit this category that Western States has utilized include High Velocity and Super Duty excelsior blankets, jute netting, and North American Green's S-150 and SC-150.

Even though I feel jute netting is a superior product, its large mesh openings require that hay/straw or hydromulch is used beneath the netting. This results in a very expensive application. The Super Duty or High Velocity excelsior blanket appears to be able to prevent erosion on steep slopes and higher velocity drainage channels as witnessed on Western States' projects. The North American Green products also provide adequate erosion protection under these same conditions, but is slightly higher in cost than excelsior blankets. To date, only manufacturers of excelsior blankets appear to have documented data on high intensity storm events or high velocity flows relative to erosion control potential.

CONCLUSION

In summary, hopefully some of the products and techniques which I have presented will be beneficial to those of you who are faced with difficult revegetation and erosion control problems. For those techniques or materials which we question their successful applications, I would like to encourage additional research by those individuals with the expertise and funding to do so.

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

SOIL GENESIS OF MINE SPOIL, NAVAJO MINE, NEW MEXICO

Bruce A. Buchanan[1], Howard C. Stutz[2] and Orlando J. Estrada[3]

ABSTRACT

Documenting mine spoil genesis has been limited in the Western States. Few areas have "before" and "after" type data and for some mines older reclamation areas are limited. Soil samples were collected from 8-11 year old reclaimed spoil as part of a rooting depth study completed in June 1987 at the Navajo Mine. Samples were collected in 25 cm increments to depths of at least 200 cm and most often to 350 cm at a total of fifteen different reclamation plots. The spoil was composed of various amounts of shale and sandstone. The sites represented different topographic positions (swale/backslope), reclamation ages (8 to 11 years), slopes (0-15%), and topdressing treatments (with and without).

Soil samples were sieved separating the rock fragments (>2 mm) from the fine earth. Rock fragments were separated into three size classes 76-25 mm, 25-6.3 mm, 6.3-2.0 mm, coarse, medium and fine gravel respectively. The fine earth was analyzed for texture (sand, silt, clay), saturation percentage, pH, EC, Na, Ca, Mg, and SAR. The assumption was made that the physical and chemical spoil properties were originally uniform with depth. Pre-reclamation samples had not been collected from the study sites. The degree of soil genesis was determined by the deviation of the plotted physical and chemical characteristics by depth from an assumed vertical line representing pre-reclamation conditions. This technique is probably valid for large sample sizes but has limited value when applied to small sample sizes. The data presented is the average for all fifteen of the study profiles. Generally the differences for the various ages, slope and topdressing treatments were not measurable, which may be a reflection of the small sample sizes of these groups. Profiles in swales generally had more apparent change than those on backslopes and the changes seemed to occur deeper in the profile for the swales.

Coarse gravel: Average content sharply increased with depth from the surface (<10%) to 200 cm (37%) and then remained constant to 350 cm (35%). This size of rock fragment seems to be disintegrating in the upper portion of the profile and is unaffected below 200 cm.

Medium gravel: Average content remained the same with depth with a slight trend of fewer fragments in the upper 200 cm (25%) than below 200 cm (30%).

Fine gravel: Average content slightly declined with depth from 50-200 cm (20% of 15% respectively) then remained constant below 200 cm (15%). It is possible the increase in this size class in the upper profile is the result of the reduction of coarse gravel.

Fine earth: Average content is highest at the surface (even excluding topdressed sites) and

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steadily declines to the 250 cm depth. It then remains constant to 350 cm. At the surface the fine earth content is 80% and declines to 40% at 50 cm and is about 25% at 250 cm and 20% at 350 cm. This data confirms the consistent field observation that rock fragments are less competent in the upper part of these profiles and the fine earth content is greater.

Texture: The fine earth textures for the spoil varies from a clay loam to a clay with an average of about 40% sand, 20% silt and 40% clay. The distribution of sand, silt and clay seem to remain generally constant with depth.

Saturation percentage: The average remains constant (about 60%) to 150 cm then increased to over 100% at a depth of 250 cm and then remained constant to 350 cm. The apparently lower values in the upper profile and conversely high values deep in the profile are not easily explained in light of the apparent even distribution of clay throughout the profile.

pH: There was an increase in pH with depth averaging, 7.22 at 0-175 cm and 7.42 at 175-350 cm. The distribution of the pH over the 350 cm varies considerably and seems to be little changed in these materials. This may be a result of the soils high buffering capacity.

Na, Ca, Mg: Na was lowest at the surface (40 meq/l) then increased from 90 meq/l to over 100 meq/l from 50 to 175 cm respectively. Ca and Mg remained fairly constant over depth (20 meq/l and 10 meq/l respectively). They were both slightly lower at the surface and had their highest values from 50-150 cm.

SAR: the lowest value (11) occurred at the surface. Values increased with depth to about 30 at 200 cm and then remained about the same to 350 cm (slightly less than 30).

EC: The soluble salts generally followed a pattern similar to the Na distribution. About 5 dS/m at the surface and increasing to 7.5 dS/m at 50 cm. Then slightly increasing to a maximum of less than 10 dS/m at 175 cm and then remaining constant (about 8 dS/m to 350 cm.)

The major processes of genesis in the spoils at Navajo mine appear to be reduction in rock fragment content, and a redistribution of soluble salts moving from the surface to depths from 50 to 150 cm. Spoil below the 200 cm depth after 10 years appear to be unchanged by the soil forming process.

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

ACID GENERATION AND VEGETATION RESPONSE OF RECLAIMED COAL REFUSE IN UTAH: AN INTERIM REPORT

Lynn M. Kunzler[1] and **James S. Leatherwood**[2]

ABSTRACT

A series of test plots were implemented on coal refuse at the J. B. King Mine in south central Utah to determine the effects of soil depth on changes in coal refuse, surface, and subsoil pH and electrical conductivity; correlate the revegetation effectiveness with different soil depths; and compare fertilizer application rates with revegetation success. This preliminary evaluation of the effects of soil depth over coal refuse and fertilizer application rates on vegetation establishment and acid generation within the refuse material indicate that vegetation response is positively correlated with increased soil cover; the addition of fertilizer is beneficial; and sulfide-sulfur compounds will oxidize to form acidic conditions in arid environments.

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INTRODUCTION

Many coal and hardrock mine sites throughout the western region of the United States are experiencing acid refuse problems parallel to those in the eastern states (Harvey and Dollhopf, 1985; Fisher and Munshower, 1984). Acid production from overburden and abandoned local carbonaceous refuse has been identified in Wyoming, New Mexico, Montana, Utah, Colorado, and Texas (Leatherwood and Kunzler, 1989; Boon, 1986; Boon and Smith, 1985; Fisher and Munshower, 1984; and, Arora and others, 1980).

In Utah, coal and associated strata are considered to have a low pyrite content and therefore, a low probability of producing acidic conditions. However, while it is generally found that coal may be low in pyrites, the strata associated with coal beds do contain high levels of pyrite. There is a concern that coal refuse and other materials high in pyrite may be acid- and toxic-forming and could potentially degrade the hydrologic balance and environmental ecosystem if not properly managed.

Variables that control acid production from pyrite materials and organic sulfur compounds include: (1) surface area; (2) ferric iron content; (3) partial pressure of oxygen; (4) form of pyritic sulfur; (5) catalytic agents; (6) pH; (7) thiobacillis or ferrobacillus microorganisms; and, most importantly, (8) water (Brown, 1985; Brunynesteyn and Hackl, 1982; and Caruccio and Giedel, 1978). Acid-forming materials may remain stable for many years because of limited pyrite surface area exposure or other oxidation rate controlling factors such as water. Once oxidation begins, however, it becomes self generating, and all acid-producing mechanisms synergistically interact (Caruccio and Geidel, 1978).

Compounding vegetation establishment on coal refuse is its dark (black) color and the attendant increased surface temperature (White and others, 1982). Croft and others (1987), Dove and others (1987), Ferguson and Frischknecht (1985), Barth (1984), Hargis and Redente (1984), McGinnies and Nicholas (1980), and Cook and others (1974) recommend that coal refuse be covered with a thin veneer of soil to mitigate any adverse qualities of the refuse. The range of recommended thickness varies from 10 to 46 cm, however most agree a minimum of 20 cm is necessary to provide adequate cover over coal refuse to prevent upward migration of salts. If too little cover is used over coal refuse, the cover material may become contaminated due to the upward migration of salts or acid water from the underlying coal refuse. The rate of this upward migration is dependent upon soil physical characteristics, such as: (1) the texture of the overlying soil; (2) the concentration gradients between the overlying soil and toxic material; (3) precipitation and evaporation regimes of the area; and, (4) the soil water flow (Hanks and Ashcroft, 1980).

Toxic materials most commonly associated with coal development are derived from saline and sodic strata, usually formed in saline marine environments. Saline materials become a problem when salt concentrates in the rooting medium increasing the soil osmotic potential and reducing available water to vegetation. In some cases, high concentrations of ions associated with salts such as sodium and boron may be toxic to vegetation. In sodic soils, sodium dominates the exchange phase of the clay mineral. This causes the clays to disperse and greatly reduce both the air and water that can enter into the soil (Donahue and others, 1977).

The Surface Mine Control and Reclamation Act of 1977 (SMCRA) requires the identification and control of potential acid-or toxic-forming materials (PATFM) in permitting and reclamation of surface and underground coal mines. The finding of reclaimability, determination of adequacy, materials handling, cumulative hydrologic impact assessment, and bonding are directly related to the presence of PATFM. The SMCRA geologic description requires "chemical analysis...of those horizons which contain potential acid- or toxic-forming, or alkalinity producing materials." Specific sample and analytical methodologies accepted by the State of Utah have been outlined by Leatherwood and Duce (1987). Regulations require PATFM to be disposed of in such a manner to render negligible environmental degradation to the hydrologic balance or vegetation communities. Currently, coal refuse is to be buried to a minimum depth of 4 feet with non-toxic material, unless it can be shown that the revegetation and hydrologic quality protection requirements will be met with less cover.

LOCATION AND PHYSICAL SETTING

The study area lies on the east central perimeter of the Emery coal field, located in southern Castle Valley between the Fish Lake Mountains on the west and the San Rafael Swell on the east. Vegetation in this area is typical of the salt desert shrubland. Land use consists of cattle grazing, recreation, and wildlife habitat.

The Early Cretaceous Ferron Sandstone Member of the Mancos Shale is the dominant rock cropping out in the study area. All coal beds are included in the Ferron Sandstone. Strata dips 1 to 2 degrees to the west and northwest. The structure of the area is controlled by the San Rafael Swell, a large anticline located east of the mining area.

Drainage is ephemeral and flows only in direct response to snowmelt or precipitation. The area is arid with precipitation ranging from 15 to 24 cm annually. Summer temperatures range from a low of -9°C to a high of 33°C while winter temperatures vary from -21°C to a high of 24°C. It is expected that potential evapotranspiration is higher than incoming precipitation; however, this has not been investigated to date.

The study-area soils consist primarily of borrow material removed from the Castle Valley soil series, extremely rocky, very fine sandy loam. These soils are taxonomically classified as loamy, mixed, mesic, lithic, Xerollic Haplargid. Natural undisturbed soil permeability is generally moderate. The soils are generally colluvium and residual derived from sandstone and shale (Western States Minerals Corporation, 1985).

METHODS

The study area, approximately 0.4 hectares in size, was established on the uppermost portion of a 4.4 hectare coal refuse pile during reclamation of the site in 1985. The coal refuse was generated from coal washing operation. A factorial, or split block design test plot was used. Treatment blocks were stratified with soil cover depth (0, 15, 30, and 60 cm) and fertilizer rate (168 kg/ha of urea and 56 kg/ha of triple super phosphate, 1/2 rate and no fertilizer) as variables. Each treatment was replicated once. The remaining portion of the refuse pile was covered with 120 cm of soil and fertilized at the full rate (fig. 1). All plots were seeded with the species and rates indicated on Table 1. In addition, Atriplex canescens, A. confertifolia, A. tridentata and Ephedra viridis seedlings were planted in rows across the soil depth treatments on the no-fertilizer treatment.

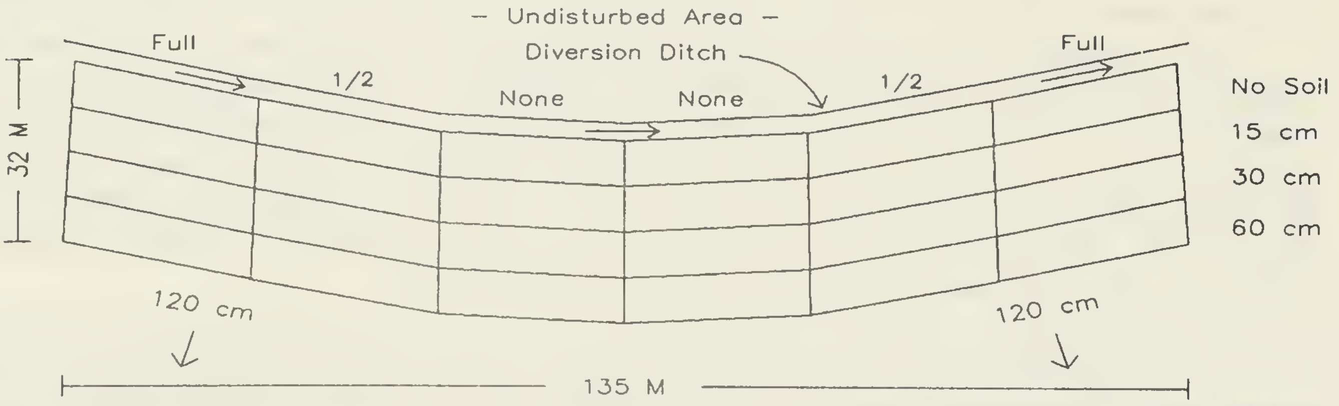

Figure 1 - Test plot design.

Species	Rate*	Species	Rate	Species	Rate
Agropyron dasystachyum	4.48	Oryzopsis hymenoides	4.48	Artemisia frigida	0.56
A. inerme	2.24	Poa ampla	1.12	Atriplex canescens	2.24
A. riparium	2.24	Stipa comata	2.24	A. confertifolia	2.24
A. smithii	4.48			Ceratoides lanata	2.24
Bouteloua curtipendula	2.24	Melilotus officinalis	2.24	Chrysothamnus nauseosus	0.56
B. gracilis	3.36	Penstemon palmeri	0.56		
Hilaria jamesii	2.24	Sphaeralcea grossulariaefolia	0.56		

* Rate is Kilograms of Pure Live Seed per Hectare.

Table 1 - Seed mixture.

The refuse pile was ripped to a depth of 45 cm prior to placement of the soil material. The final graded surface had a 2% slope with a south-westerly aspect. A diversion ditch at the top of the test plots prevented runoff from surrounding areas from running onto the plots.

Electrical conductivity extract (ECe) and pH were evaluated to establish the physiochemical effects of the refuse material on the soil cover. Water soluble phosphorus and water soluble nitrogen were also evaluated. Samples were taken from the upper 15 cm of soil, soil-refuse interface, and underlying refuse in each plot. Three samples of each material were analyzed from each plot to obtain average parameter values. ECe, pH, water-soluble phosphorus, and water-soluble nitrogen measurements were conducted on field samples using a Hach Field Soil Analyzer.

To determine if acidification or salinization is occurring in the coal refuse or soil cover, pH and ECe were monitored in 1987 and 1988 on the no-fertilizer plots only. Monitoring did not take place on the plots receiving fertilizer due to the potential of the fertilizer to affect pH and ECe values. The effects of fertilization on pH and ECe with the coal refuse interface and soil cover was not analyzed. This will be studied at a later date.

All treatment plots were monitored for species composition and vegetation cover (cover by species and total aerial cover) during 1988 and 1989, using a 1 m square quadrate and estimating cover to the nearest percent (Kunzler and Linner, 1982). In 1989, data was also collected from the area adjacent to the testplot where the soil depth was 120 cm since a preliminary evaluation of the 1988 data showed increased response to soil depth to the 60 cm treatment. Shrub transplants were monitored for survival and vigor (determined by height of individual plants) during 1988. Data was subjected to regression analysis and multivariate analysis of variance (ANOVA).

RESULTS AND DISCUSSION

Acid Generation

Comparison of pH by treatment depth for both 1987 and 1988 indicates a decreasing trend from the soil to interface to refuse profiles. The average pH values for the 1987 pH soil, interface, and refuse samples were 7.2, 6.7 and 6.6; and in 1988 the same averages were 7.3, 6.7, and 5.9, respectively. The pH values for soil remained relatively constant from 1987 to 1988 for all treatments. The interface exhibited a slight increase in pH at the 15 and 30 cm depths, and a large decrease in pH from 6.7 to 5.9 at the 60 cm depth. Refuse with no cover had increased pH values from 1987 to 1988. The increase in pH of the refuse with no cover may possibly be from the depletion of pyrite generated acids and neutralization by contaminants from surrounding soils via runoff and/or wind erosion. The pH of all refuse beneath the 15, 30 and 60 cm treatment decreased in pH from 1987 to 1988. The refuse in the 15 cm treatment decreased from 6.9 in 1987 to 5.6 in 1988. The refuse in the 30 cm treatment decreased from 7.0 in 1987 to 5.7 in 1988. The pH value from the 60 cm treatment changed the most with an average change from 7.1 to 5.1 for 1987 and 1988, respectively (Table 2).

Soil Depth	0		15		30		60	
Year	'87	'88	'87	'88	'87	'88	'87	'88
Soil	--	--	7.1	7.4	7.2	7.3	7.1	7.2
Interface	--	--	6.7	6.8	6.7	7.1	6.7	5.9
Refuse	6.4	7.2	6.9	5.6	7.0	5.7	7.1	5.1

Table 2 - Comparison of soil, interface, and refuse pH, 1987 - 1988.

The soil, interface, and refuse had ECe values greater than 4.0 mmho/cm and are considered saline. Values ranged from 4.9 to 9.7 mmho/cm with an average of 7.2 mmho/cm. The ECe of the soil was relatively less than that of the interface zone and the refuse. Refuse ECe values decreased in the no-soil cover treatment but increased in all other treatments between 1987 and 1988 (fig. 2).

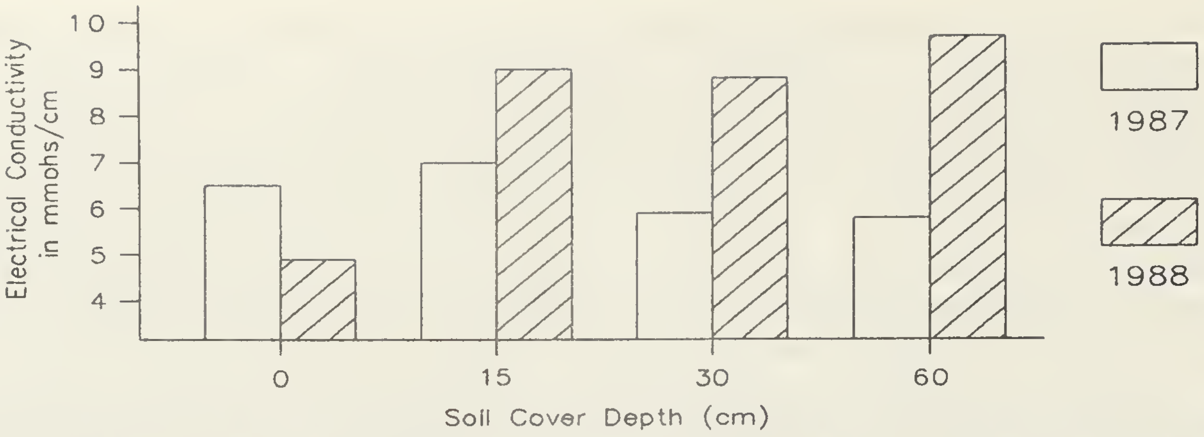

Figure 2 - Comparison of electrical conductivity of refuse and soil cover depth over refuse, 1987 - 1988.

The authors hypothesize that the change in pH and the ECe values are directly related to the water flow characteristics and amount of water available for the oxidation processes. During reclamation of the mine site, the refuse material was broken up at the surface to increase the contact with the cover material. This operation may have produced a lens of less dense material. During large precipitation events, the infiltrating water would move through the uncovered refuse, into and within this lens. During the more prevalent dry spells, the soil becomes dried out, impeding the upward migration of water (Donahue and others, 1977). The test plot slope, decreasing from the no cover to the 60 cm depth, allows water to be transported from the no cover and possibly 15 cm treatment by either saturated or most likely unsaturated flow to the 60 cm treatment. Water retained in the deeper treatments would be available for sulfide oxidation processes. This hypothesis is supported by the decreasing refuse pH values from 1987 to 1988 for the 15, 30, and 60 cm treatments.

The hypothesized relationship of pH and water movement and availability supports Snyder and Caruccio's (1988) conclusion that water and its pathways play a critical role in the acidification process through mass transfer and production of acidity and alkalinity. The hydrology (event recharge, pore distribution, porosity, acid base potential, residence time and outflow) of the backfilled refuse and soil cover will be the keystone for effective management of all potential acid- or toxic-forming materials. Infiltration rates, permeability, and vadose zone monitoring have not been established at the test site to date. Monitoring of these hydrologic parameters is recommended for future analyses.

Vegetation Response

Vegetation cover was found to have a linear relationship with increasing soil depth, with total cover values for both the 1988 and 1989 data (fig. 3). This relationship is more clearly defined if one looks only at the contribution of desirable species (fig. 4). These data support the findings of McGinnies and Nicholas (1980) who also found vegetation response to soil depth to be linear, and is generally supported by others (Barth 1984, Narten and others, 1983, and Cook and others, 1974) who have recommended greater than 20 cm soil cover over refuse is needed for successful reclamation. As can be noted from the data presented in figure 3, there was a marked decrease in total cover from 1988 to 1989. This reduction is believed to be a result of drought conditions during 1989. Weedy annual species which depend on adequate moisture for germination each year would show greater reduction over established perennial species that only need to sustain their existence during longterm drought. An examination of the contribution of both annual weeds and the perennial (desirable) species illustrates this type of a relationship (fig. 5). In 1988, weeds contributed 76% of the total vegetation cover compared to only 56% in 1989. This represents a two-thirds reduction in weed cover, compared to only one-fifth reduction of desirable species cover. ANOVA showed the relationship of soil depth to be significant (F= 3.474) for total cover. The relationship is even greater for the desirable species (F= 1.85). One explanation for this is that cover of weedy species were usually greater on the no-soil and 15 cm treatments (fig. 6), with individual samples often exceeding the cover values for total cover of the deeper soil treatments (one sample had 90% weed cover).

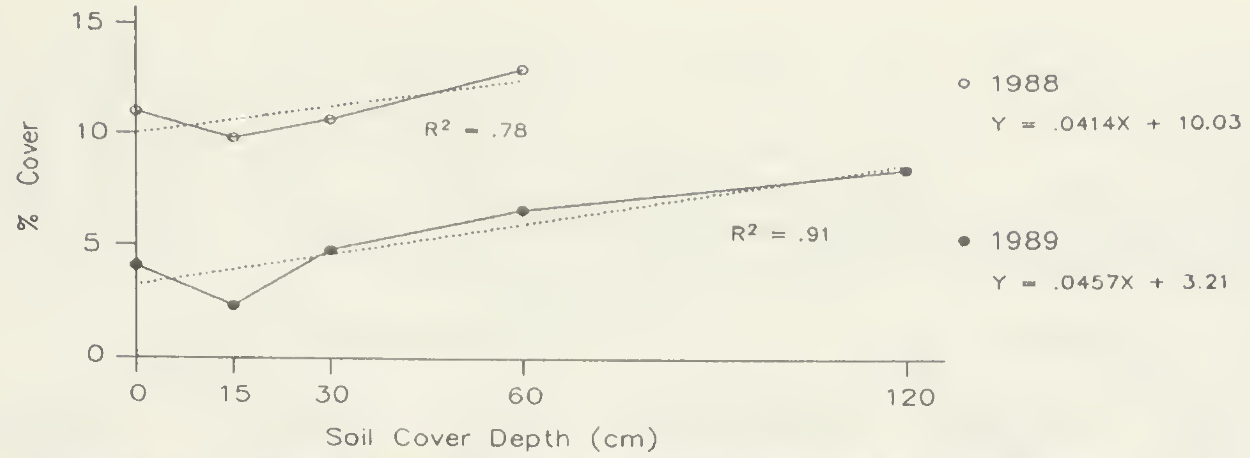

Figure 3 - Comparison of total vegetation cover and soil cover depth over refuse, 1988 - 1989.

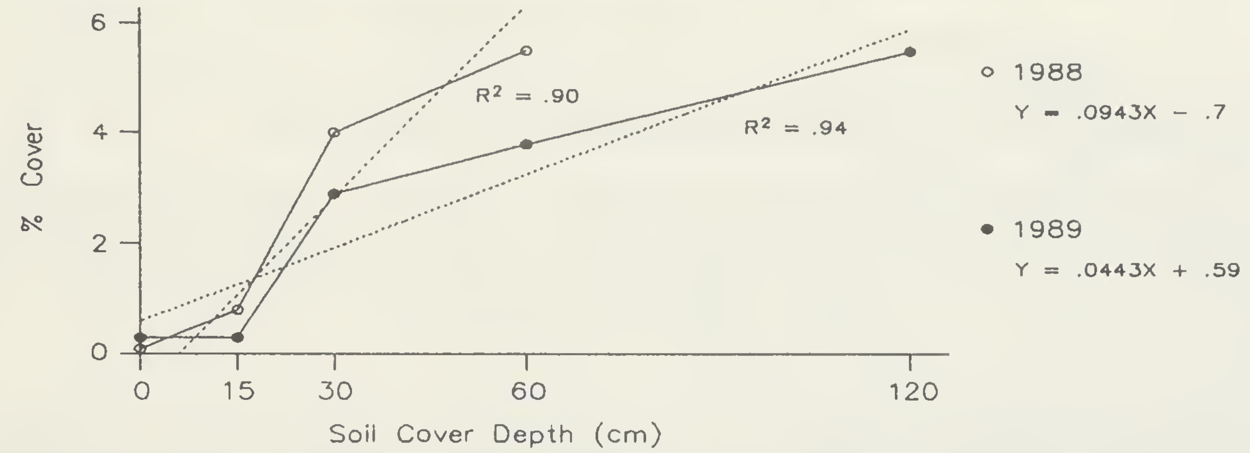

Figure 4 - Comparison of vegetation cover of desirable species and soil cover depth, 1988 - 1989.

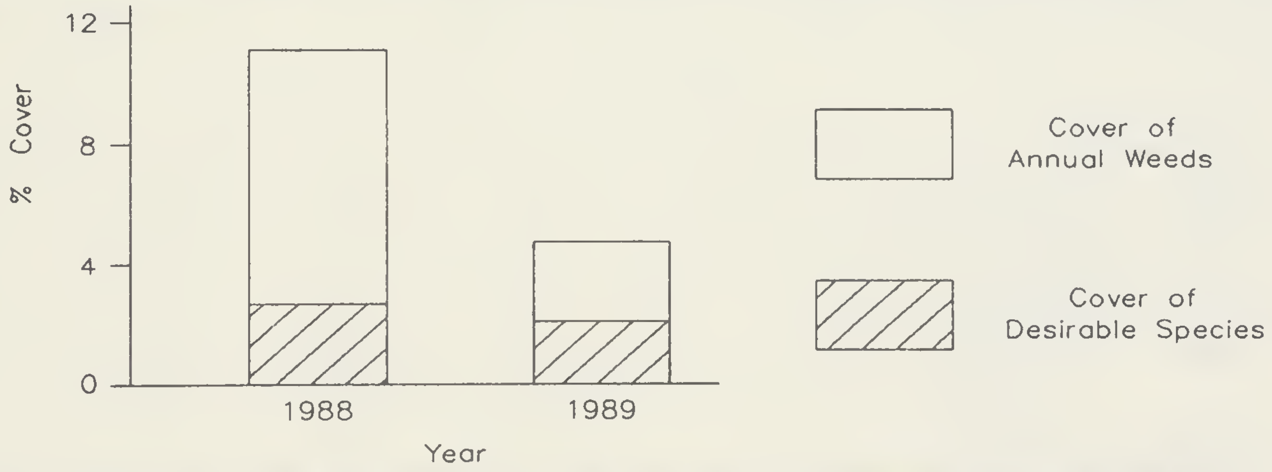

Figure 5 - Contribution of desirable species and annual weeds to total vegetation cover, 1988 - 1989.

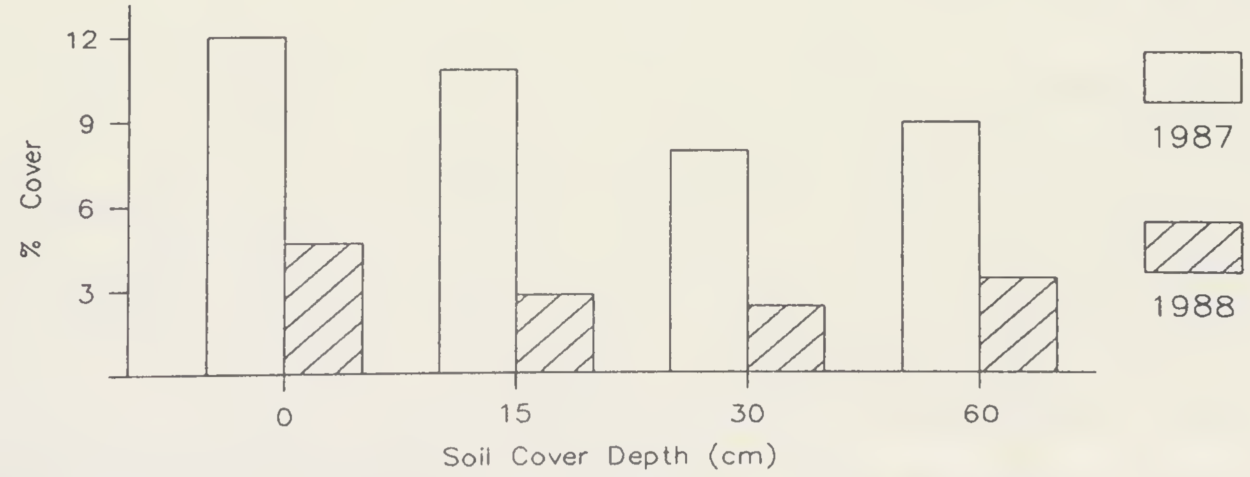

Figure 6 - Comparison of % cover of annual weeds and soil cover depth, 1988 - 1989.

The effects of fertilizer on total cover were significantly different (as per a t-test) between fertilizer treatments in 1988, indicating an increase in cover due to an increase in fertilizer. However, in 1989, total cover was not significantly different for each fertilizer treatment. By looking only at the desirable species, percent cover of the full fertilizer treatment was significantly different (greater), thus demonstrating a positive response to fertilizer treatment on at least the desirable species into the fourth growing season (Table 3). There was no significant difference in the annual weed cover as a result of fertilizer rate.

	1988			1989	
Rate*	Percent Total Cover	Percent Cover of Desirable Species	Rate	Percent Total Cover	Percent Cover of Desirable Species
F	11.9	3.6	F	4.7 B	2.4
H	11.6	2.3 A	H	4.3 B	1.5 C
N	9.8	2.1 A	N	4.4 B	1.6 C

* F = full fertilizer rate H = 1/2 fertilizer rate N = no fertilizer

Same letters in columns indicate no significant difference at the 90% confidence level.

Table 3 - Comparison of fertilizer rate and percent vegetation cover, 1988 - 1989.

Shrub survival and vigor data are summarized on Table 4. Survival of the shrub transplants was greatest with Atriplex tridentata (54.5%) followed by A. canescens (18.9%) and A. confertifolia (11.4%) There was no survival of Ephedra viridis seedlings. Average height differences between species is believed to be simply the growth characteristics of the individual species. However, the differences between soil depth is a function of the treatment. These data indicate that soil depth for shrub survival and vigor are positively correlated (figs. 7 & 8). Optimal soil depth was probably not achieved within the plot design. Observations of shrubs off the test plot area (established from seed and transplants) showed higher vigor. However, because the full fertilizer rate was used on these areas, comparisons would not be valid since it would be impossible to separate the effects of the fertilizer and plant material type from the soil depth effects on these more robust plants.

Soil Depth (cm)		0	15	30	60	Total
Atca	% Survival	0	3.0	21.2	51.5	18.9
	Ave. Height		25.4	33.8	50.3	
Atco	% Survival	0	9.1	9.1	27.3	11.4
	Ave. Height		12.7	20.3	27.2	
Atga	% Survival	0	27.3	90.9	100.0	54.5
	Ave. Height		8.4	14.7	23.1	
Totals	% Survival	0	9.1	32.7	56.4	24.5

Table 4 - Shrub survival and average height of shrubs by species for each soil depth treatment.

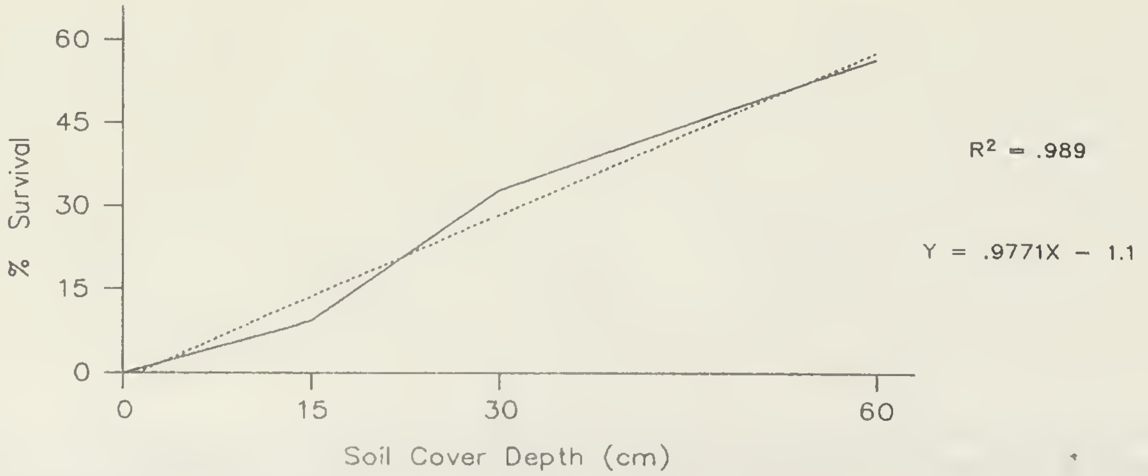

Figure 7 - Comparison of shrub survival and soil cover depth over refuse.

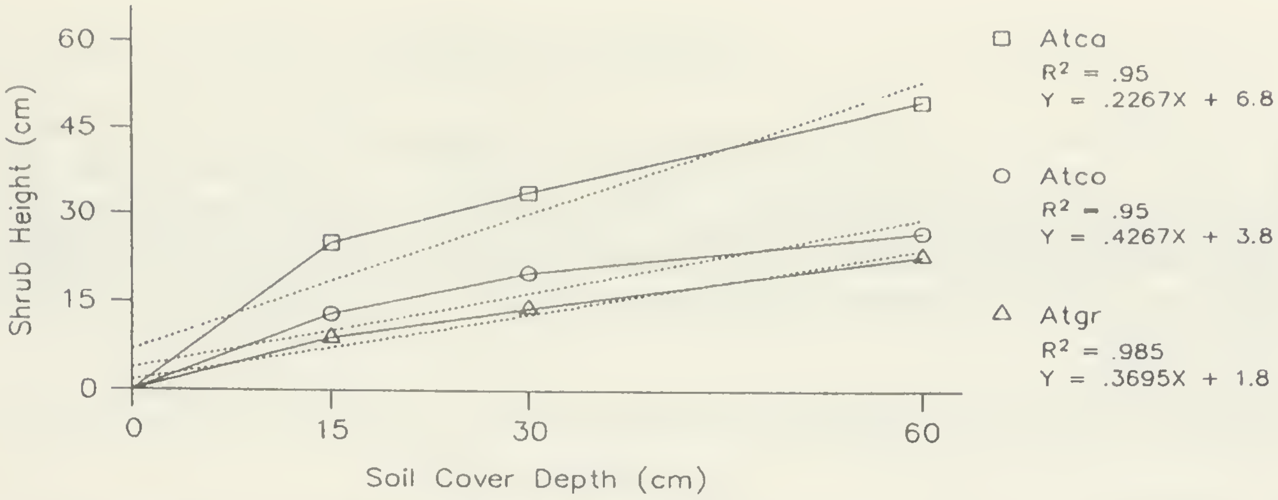

Figure 8 - Comparison of shrub height and soil cover depth over refuse.

The effects of acid generation on vegetation response cannot be determined from this study. A cursory look at the data would lead to the probable false conclusion that vegetation is positively affected by acidification, since both the lowest pH values and highest cover values were obtained from the greatest soil depth treatments. However, to make this conclusion, one must have data from treatment blocks where there was no acidificatation.

SUMMARY AND CONCLUSION

Two years of sampling indicate that geologic strata high in pyritic sulfur associated with the coal fields in the arid regions of Utah will oxidize to form acidic conditions. A decrease in pH values were associated with an increase in electrical conductivity in all treatments except the treatment with no cover material where it is believed precipitation leached the dissolved solids out of the sample zone.

The refuse pH decreased over time and is expected to do so in the future until physiochemical equilibrium is established with the system. The refuse pH values decreased as the depth of cover increased from no cover to 60 cm of cover. This pH relationship is assumed to be hydrologically related. Poor infiltration rate of the soil and a high refuse infiltration rate cause the incoming water to diffuse through the refuse plot allowing the acidification and transportation of the dissolved solids to occur. At the 60 cm treatment, the deficit water caused by a postulated higher rate of evapotranspiration than the other treatments pulls the water and associated dissolved salts out of the refuse, into the soil. The rate of pyrite oxidation occurring at the 15 and 30 cm treatments is slower than the no cover or 60 cm treatments due to water availability.

An understanding of refuse backfill hydrology will be instrumental in developing effective and efficient disposal management of potential acid- or toxic-forming materials. Regulatory authorities and mining personnel have commonly approached this problem under the assumption of a uniform wetting front, when in fact, the majority of the water flow, and associated physiochemical reactions, are possibly occurring along more permeable zones. Further research into soil and refuse hydrologic dynamics and physiochemical interactions are required.

Vegetation response, as measured by cover, species composition and shrub survival and vigor increased as soil depth over coal refuse increased. Data show that cover increased linearly with increased soil depth to 120 cm. Since plant establishment is greatest on the 120 cm treatment, optimal soil depth cannot be ascertained. However, less than 30 cm of soil has not provided favorable vegetation response. This does not necessarily mean that all coal refuse piles must be covered with 120 cm during reclamation. The scope of this paper did not include comparisons of treatments with the revegetation success standard. It is feasible that adequate vegetation may be established with less than 120 cm of soil cover. This study, however, does support site specific examinations to demonstrate adequate vegetation establishment can be achieved if less than the regulated "4-foot" cover is desired.

Fertilizer had a positive effect on vegetation, more notably on desired perennial species. However a preferred rate cannot be determined from this study. Further investigation is warranted.

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Planning, Rehabilitation and Treatment of Disturbed Lands
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SOIL SALVAGE EVOLUTION AT THE ROSEBUD MINE

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ABSTRACT

Prior to 1968 soil salvage was unheard of in surface mining terminology. Soil was moved by dragline or truck and shovel right along with the other material, or "overburden", lying above the coal seam. Remnants of mining without regard for soil salvage from 1923 ro 1958 can still be seen at the Rosebud Mine. From 1968 to 1973 during the energy shortage and subsequent environmental awareness, miners, regulators private resource groups and researchers began looking for methods to improve reclamation. Initially, several surface manipulations were tried on overburden without soil salvage. Finally by 1973, some soil salvage was attempted. These early attempts consisted of one lift operations where all soil was stockpiled. From 1973 to 1978 several soil studies were completed at the Rosebud Mine. A soil wedge study determined that approximately two feet of soil was all that was needed at the Colstrip area. Another study found that land classifications could be improved by placing uniform soil depths on stable slopes. These, and other similar studies led to Western Energy Company's present two lift soil salvage program. A "direct haul" salvage system has also been instituted to cut salvage costs and benefit from the viable native seeds and mycorrhiza available in the soil. Stockpiling now occurs only where regraded sites are not available. Today, some soils receive special handling. "Tree soil" is salvaged by one two foot lift and placed on sites conductive to tree establishement. Special operational activities, however, must be considered along with costs and reclamation benefits before incorporating them into the operations. Soil operations must be kept as simple as possible to be cost effective and to eliminate regulatory problems.

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INTRODUCTION

Mining began at the Rosebud Mine in 1923 by the Northern Pacific railroad. The purpose was to mine coal to power locomotives. Mining lasted until 1957 when the railroad locomotives switched from coal to diesel fuel. During the period from 1923 to 1957, virtually no reclamation was done. All soil was removed by dragline along with overburden.

In 1967, Montana Power Company (MPC) purchased the Rosebud Mine and created Western Energy Company (WECO) as their coal mining subsidiary. From 1967 to 1970 MPC regraded approximately 480 acres of old spoil banks. Reclamation consisted of seeding wheat or a simple mixture of introduced grasses into the regraded spoil. At the same time, WECO began mining in Pit 6 where previous Northern Pacific mining had stopped. Although reclamation rules still did not exist, state rules were in the process of being enacted. Knowing this, WECO's initial mining included some limited reclamation, consisting of regrading new spoils. The planting medium or "soil" consisted of whatever spoil\soil mixture was left on the regraded surface.

SURFACE MANIPULATIONS

Since new rules requiring reclamation were on the horizon, WECO initiated several research studies with the Montana Agriculture Experiment Station at Montana State University to gather data on how to reclaim mined land on the most cost-effective manner.

Rather than salvage soil, surface manipulations and soil amendments were used in attempts to enhance plant establishment on regraded spoil. Three surface manipulations that were used consisted of dozer basins, gouging, and deep chiseling (Sindelar, 1974). All initial surface manipulations were done on untopsoiled regraded spoils. Results varied, and at sites where sandy-textured spoil occurred on the surface, vegetation establishment of the introduced species was somewhat successful. At sites of dense clay shale spoil, plant establishment was much poorer. Some of the dozer basins, in area of poor vegetation establishment, over-filled with run-off after a precipitation event and caused erosion through a chain-reaction of over-flowing dozer basins. The gouger created minature dozer basins to accumlate water for infiltration into the spoil in order to assist establishing plants seeded in the basins. A gouging procedure was improved upon later by the construction of a "seeder-gouger" whereby seed was broadcast at the same time with the same machine.

Fertilizers and temporary stabilization with annual vegetation were also used to improve conditions for seeding into regraded spoil. This seemed to improve reclamation as did the various surface manipulations, but emphasis was still placed on using spoil as the plant rooting medium, rather than salvage soil.

SOIL SALVAGE

As research continued, many of the studies indicated the need for soil. Even the surface manipulation studies began to be conducted in "topsoiled" areas. Some of the temporary stabilization studies were conducted on areas where "thin layers" of topsoil had been applied, (Sindelar, 1974). It didn't take long for researchers and reclamationists to realize that soil salvage was the key to reclamation success.

After the Montana Strip Mining and Reclamation Act was enacted, soil salvage was required by law. At first soil salvage at the Rosebud Mine consisted of one lift mixing both topsoil and subsoil. Most of this type of single lift salvage occurred from 1973 to 1977 and plant establishment was much better. Initially most soil was stockpiled to be placed on a regraded surface at a later date. While the process of stockpiling soil for later use was vital to successful reclamation it was also found that stockpiling had detrimental impacts on soil microorganism populations and physical properties of the soil. When topsoil from stockpiles was replaced on regraded surfaces, it was of decreased quality and was less effective than it's original form (Sindelar, 1974). Studies on use of stockpiled soil led to current "direct haul" or direct placement of soil.

By the time the Federal Surface Mining Reclamation Act (SCMRA) was enacted in 1978, two lift salvage of soil was required by both state and federal rules. By then WECO was salvaging the A and upper B horizons as "topsoil" seperately from the lower B and C horizon or "subsoil". Soil salvage depths ranged from one-half to one-foot of topsoil and from one to three foot of subsoil dependent upon the soil series.

In an effort to more accurately salvage the proper amount of soil, WECO initiated a pre-mine soil sampling program. Prior to every stripping pass, each soil series was individually sampled to determine salvageable depths.

With the two lift soil salvage method in use, direct haul began to be employed more and more. Obviously during boxcut operations, there is no regraded area for direct haul soil placement and therefore all soil must be stockpiled. Once a dragline makes a third pass (each pass at the Rosebud Mine is 180-feet wide), rule 26.4.501A of the Montana rules, (State of Montana, 1980) requires that regrading be kept current with mining, therefore the first pass must be regraded. This rule states that no more than two spoil ridges may be left standing and allows for direct placement of soil on the regraded portions of the first dragline pass. Soil is hauled around the pit, and if necessary over a crosspit ramp built to shorten haul distance. With direct hauling, soil salvage costs can be cut in half, since soil is only handled once. Today it is standard procedure for WECO to plan ahead in order to direct haul soil whenever possible.

Another distinct advantage of direct hauling is the successful establishment of a myriad of grass, forb and shrub species. Grasses that readily establish at the Rosebud Mine through direct haul soil consist of needle-and-thread grass (*Stipa* comata), *sand bluestem* (Andropogon *hallii*), and prairie sand reed grass (*Calomovilfa longifolia*). Perhaps the only chance for the establishement of threadleaf sedge (*Carex filifolia*) is through direct hauling. Sod chunks of this sedge laid down immediately after stripping have established this species in WECO's reclamation.

Volunteer forbs are also readily observed in direct haul areas. Forbs such as fringed sagewort (*Artmesia frigida*), cudweed sagewort (*Artemesia ludovicoana*), silverleaf scurfpea (*Psoralia argophylla*), and common salsify (*Tragapogon dubius*) establish readily along with the seeded species.

Some shrubs that readily volunteer consist of wood's rose (*Rosa woodsii* and snowberry (*Symphoricarpos occidentalis*).

A good example of how effective direct haul can be was the discovery of common garden irises (*Iris species*) growing in WECO's reclamation. A vacant farm homesite had been mined and the iris bulbs from the farm flower garden had been transplanted by direct haul.

A soil "wedge" study indicated that placing soil deeper than two and a half feet did not yield better plant establishment or production, (Barth, 1982). At that time WECO was salvaging and redistributing soil at some sites at depths of four to five feet.

Barth's research led WECO to reduce soil redistribution to a maximum of two and a half feet total depth. Most salvage also does not exceed three-feet maximum since enough material can be salvaged to establish an effective native reclaimed rangeland with two and a half feet of soil depth.

"RECLAMATION VS RESTORATION"

Another study at the Rosebud Mine (Schafer, 1982) indicated that soil classifications could be improved through reclamation. Capability classes at the IV and V level could be improved to Classes III and IV, respectively, by reclaiming the land to reduced slopes and by the placement of uniform topsoil depths.

Schafer's work helped promote a philosophy that reclamation can actually improve rangeland conditions. After surface mining and reclamation, it must be acknowledged that change will occur. The aesthetic landscape of rough, broken, country parted by dissected draws and coulees of varying topsoil depths will be replaced by a smooth, rolling landscape with gentle slopes and uniform topsoil depths. Surface mining has a "glacial effect" on the land and Schafer's work indicated that this is not necessarily bad. Much of the land can actually be improved through reclamation!

By the mid-1980's WECO had developed a very good soil salvage program. Enough data had been gathered through the pre-salvage sampling program that it was eliminated. In replacement, WECO initiated a post-mine soil depth sampling program whereby samples are collected every 300-feet on redistributed soil for depth, texture, ph and EC. Soil salvage did not exceed two and a half feet in depth and direct hauling was considered most important in mine planning.

At the same time, however, questions regarding rooting zones for different plant communities arose during permitting procedures. After much deliberation on the subject, stipulations were placed on new permits requiring plans to accommodate for varying rooting depths for different plant communities. These stipulations led WECO to initiate a special soil salvage program. Normal soil salvage still continued with a two lift operation, but for ponderosa pine (Pinus Ponderosa) reclamation, a special handling of specific soil deemed "tree soil" was initiated. Some poor quality soil complexes associated with pines prior to mining were salvaged by one lift and stockpiled separately during stockpiling operations in boxcuts or hauled to regraded areas during direct haul procedures.

Since the initiation of the tree soil salvage program, several operational problems occurred prompting WECO to question the need for this type of special handling.

Roughly half of the material salvaged as tree soil is no different than spoil material. Erosion of these "tree" soils on redistributed slopes were common due to the fine clay loam composition. The other half of material salvaged as tree soil was so rocky it was difficult to handle with the equipment and impossible to seed by normal methods once placed. Hydroseeding, an expensive alternative, was the only option in these situations. At many sites, when tree soil was available for salvage, the regraded areas of the right aspect were not available, causing stockpiling rather then direct haul. When direct hauling ceases and stockpiling begins unnessarily the value of "special handing", must be questioned.

This same permit stipulation requires WECO to restore questionable badland habitats. These types of habitat were created due to the erosive nature of an unglaciated area. Reclaiming types such as this is more analogous to restoration. Proper restoration of questionable "bad lands" would most closely represent pre-mine habitats by not redistributing soil! This leads reclamationists to question where the future of reclamation leads. Regulators must remember surface mining's past and relish the progress made by state and federal rules requiring soil to be salvaged for proper reclamation.

SUMMARY

A brief review of the evolution of reclamation and soil salvage consists of:

- Regrading of spoil banks.
- Surface manipulations.
- Soil Amendments.
- One lift soil salvage and stockpiling.
- Direct haul vs. stockpiling.
- Two lift soil salvage.
- Two and a half foot maximum depth of soil redistribution.
- Reduced slopes.

These steps appear very progressive, but the following two appear to take a different direction:

- Special hauling of specific poor quality "tree soil" for pine establishments.

- Restoration of bad lands by special hauling "non-soil" from pre-mine sites or by leaving spoil peaks.

It appears, the reclamation business has come full circle, back to where it started in 1967. Salvaging "tree and badlands" soil with original capability classes of VII or higher, is not in anyone's best interest. Soil operations should be kept as simple as possible and special handling should be avoided. In summary, a good reclamation philosophy should be to "keep it simple".

Regrade to stable slopes, and salvage all available quality soil It must be acknowledged that surface mining through rough, broken dissected land will have a "glacial" effect on the reclaimed surface, and that changes will occur, although it will not necessarily be for the worse. Good productive land with good soils will be left for future generations to come!

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Effect of seeded grass, soil texture, and salinity on steppe community composition--eighth year observations of a three-factor experiment.

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ABSTRACT

A field experiment in a high plains environment (Decker, Montana, USA) compares the effects of soil texture and salinity on community development on plots seeded with three regional dominants (Bouteloua gracilis, Agropyron smithii, and Stipa viridula), four other native Agropyrons (A. dasystachyum, A inerme, A riparium, and A trachycaulum), four oft-planted exotic grasses (Agropyron cristatum, A trichophorum, Elymus angustus, and E junceus), and the major grass crop of the region (Triticum aestivum). Eighteen soil pads 20 x 50 x 2 feet were created over normal fill. Three clays, three loams, and three sands from the Fort Union Formation were used to simulate the effects of surfacing with soils of different textures. Two salting levels (0 and approximately 5 mmhos) were used to simulate the effects of non-saline and saline conditions. Five by five foot plots on each soil pad were seeded to each of the species studied and presence, cover, and standing crop were recorded after 2, 4, and 8 years. Eighth year observations show: 1) that the planted species differ significantly in their abilities to establish, persist, produce, spread, and resist the invasion of both desirable and undesirable species; 2) that soil texture has long term effects on these responses; and 3) that, while salinity affected establishment, leaching during the period has largely eliminated its influence.

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Introduction

Ecologists believe that community qualities are determined by factors including temperature, moisture, substrate, and flora available (eg Crocker and Major 1955). Evidence supporting this belief is often correlations observed in field situations where factors such as climate and soils are thoroughly confounded. Bradshaw (1983) points out that current mine reclamation projects offer exceptional opportunities for ecologists to initiate experiments that will rigorously test their theories. The reclamation medium can elegantly separate climate and soil factors (cf Marsten-Jones and Turrill 1945).

Our work seeks to determine the effects-- in a steppe climate (Weaver 1980, types 16, 56 and 64)-- of soil texture, initial soil salinity, and initial floristics (planted species), on community characteristics including cover, standing crop, and production of community components including shrubs, perennial grasses and forbs, and annual herbs. In 1981 we established a three-factor experiment with two salinity levels, three soil textures , twelve grass plantings and three replications. Lichthardt (1986) summarized our early observations of grass establishment (years 1,2, and 4) and herbaceous invasion (year 4). This paper summarizes our eighth-year (1989) observations of standing crop size and composition.

Methods

The climate of the study area is characterized by average annual precipitation of 37 cm (14 inches, Lichthardt 1986), summer highs of 20C, and winter lows of -10C (Weaver 1980). The landscape of the area is characteristic of Fort Union Formation and features rocky ridges and intervening valleys with deeper soils. Native vegetation of the study area consists of ponderosa pine savanna on rocky areas and semiarid grassland on deeper soils.

Eighteen soil pads were created at the Spring Creek Coal Mine to measure the effect of soil texture (nine soils) and soil salinity (two levels) on establishment of range grasses and the development of communities containing them. The experimental soils were selected from the mine, 10 km north of Decker MT, in an area representative of Fort Union Formation coal mining. Nine, previously undisturbed, subsoils with textures ranging from clayey to sandy (Table 1) were collected with earth-scrapers and used to construct nine, 27 x 4 m pads, 0.5 m deep. The pads were divided longitudinally into two subpads by a ditch over two meters wide. On half of each soil pad, a 4:1 mixture of $CaCl_2$ and NaCl (meq $CaCl_2$: meq NaCl) was incorporated to a depth of 30 cm, in amounts expected to produce electrical conductivities of 5 mmhos/cm. Salt was applied as a 1:4 milliequivalent mixture of NaCl to $CaCl_2$ (20% NaCl by weight) to prevent soil dispersion. Soils were fertilized differentially with ammonium

Table 1. Soil characteristics (water holding capacity[1], texture[2], and conductivity[3]) of the experimental plots.

						Conductivity (mmhos/cm)					
		Percent				1982, Nov.		1983, Nov.		1989, Oct.	
Soil	WHC	Clay	Silt	Sand	Stone	ns	slt	ns	slt	ns	slt
sand 1	0.15	19	32	49	10	2.5	4.1	1.0	1.0	0.7	0.7
2	0.13	20	27	53	23	1.9	3.6	1.2	1.3	0.6	0.7
3	0.14	12	31	57	24	1.0	4.3	0.4	0.5	0.8	0.8
loam 1	0.17	21	42	37	0	0.8	4.1	0.5	1.0	0.6	0.7
2	0.20	16	49	35	11	0.9	5.2	0.4	1.9	0.7	0.7
3	0.18	17	45	38	15	0.9	6.4	0.5	2.1	1.0	1.2
clay 1	0.21	32	50	18	2	2.1	6.1	1.1	2.1	0.6	0.6
2	0.21	32	49	19	8	3.0	7.0	1.9	3.7	0.6	0.6
3	0.20	39	39	22	2	2.8	10.0	1.2	4.2	1.0	0.9

[1] The water holding capacity of the fine fraction was measured as the 0.33- bar water content minus the 15-bar water content and the stone volume was subtracted on the assumption that it is non-absorptive.

[2] Sand-silt-clay percentages were measured by the hydrometer method. Stone volume percentages were calculated by assuming a bulk density of 2.65 gm/cc and bulk-density/ soil texture diagrams.

[3] Conductivities were measured in a 1:2 gm/gm soil/water mix and converted to estimated 'saturated paste' values by multiplying by four.

nitrate and ortho-phosphate to create a nearly uniform level of fertility. Details of our experimental procedure, including its randomized block design are given by Lichthardt (1986).

Twelve species were seeded into their individual plots on each pad in May of 1982. We planted five native wheatgrasses (Agropyron dasystachyum, A. inerme, A. riparium, A. smithii, and A. trachycaulum), two other natives (Bouteloua gracilis and Stipa viridula), four exotics often used in land reclamation (A. cristatum, A. trichophorum, Elymus angustus, and E. junceus) and wheat (Triticum aestivum). The seed was 'breeder class', from regional SCS plant material centers or was locally grown. A seeding rate of 1080 pure live seed/m^2 (100 PLS/ft^2) was used. The plots were never irrigated.

As an index of salinity, conductivity was measured on installation of the soil pads (November 1982) and periodically thereafter (November 1983, October 1985 and October 1989). Conductivities were measured on a 1:2 soil/water mixture and saturated paste conductivities were estimated by multiplying the measured conductivities by four.

The Northern Energy Resource Co (NERCO) environmental laboratory, Sheridan, characterized the soils initially (Lichthardt 1986) with respect to texture, organic matter (dichromate oxidation), cation exchange capacity (sodium acetate), pH (saturated paste), SAR (saturated paste extract), nitrate-N (chromotropic acid), phosphorus (Olson P), potassium and micronutrients (AB-DTPA extractable). As noted above, soils were fertilized differentially with ammonium nitrate and ortho-phosphate to create a nearly uniform level of fertility.

We measured indicators of water holding capacity and aeration of each soil at the beginning of the experiment. The texture of material passing a 2mm screen was measured by the hydrometer method and its water holding capacity (difference between 1/3 and 15-bar water) was measured with a pressure plate. Coarse fragment contents were measured on a weight basis and converted to an (estimated) volumetric basis by using bulk densities of rock (2.65 gm/cc) and soils of similar textures (Brady 1990 and J Rogers, personal communication). The development of a 'desert pavement' was recorded in 1989 by raking gravel from the surfaces of 1x 2 ft plots, sieving (2mm screen) and weighing.

Standing crop (gm/m^2) was measured in 1983 (second year), 1985, and 1989. Results for 1983 and 1985 were reported by Lichthardt (1986). In 1989, eighth-year measurements were made by clipping four, 1 x 2 ft quadrats in each species plot in early September.

Results and Discussion

FACTOR EFFECTS ON TOTAL STANDING CROP. Overall, standing crop of the Elymus angustus community (473 gm/m^2) was markedly higher than that of other communities. Standing crops were 130-150 gm/m^2 in three communities (A trichophorum, Stipa viridula and A cristatum), 118-123 gm/m^2 in four communities (A inermis, A dasystachyum, Elymus junceus, and Triticum aestivum) and 80-108 gm/m^2 in four communities (Bouteloua gracilis, A smithii, A trachycaulum, and A riparium). We attribute the large standing crop of the Elymus angustus primarily to accumulation of material across years in its coarse (ungrazable) stems rather than to a superior use of scarce resources, especially water. The relative importance of productivity vs durability in distinguishing the standing crops of other species remains undetermined.

Average community production-- estimated as standing crop of all grasses, except the accumulative Elymus angustus-- is greater on sandy (126 gm/m^2) and loamy (122 gm/m^2) than on clayey (102 gm/m^2) soils. We explain (hypothesis) this difference by noting that, in comparison with clays, coarser soils allow more water penetration and support both deeper penetration and less capillary rise of water; thus, of rain applied, less runs off coarse soil plots, a smaller fraction of the water absorbed is evaporated, and more water remains to support photosynthetically useful transpiration).

The difference between standing crop (and production) on salted (114 gm/m^2) and unsalted (121 gm/m^2) sites is small and not statistically significant. We explain the absence of a difference by noting that much of the salt applied was leached (albeit by annual precipitation averaging in 1982-1985 only 20 cm/year) out of the surface soils during the first year and most was gone by the fourth (or eighth) year (Table 1) and now has little effect on plants-- especially annuals and grasses-- rooted in the superficial layers.

FACTOR EFFECTS ON GRASS ESTABLISHMENT. Analysis of standing crop across all planted species showed significant (p=0.0001) differences among species. Elymus angustus standing crop was high (457 gm/m^2) because its coarse stems persist from year to year. Standing crops of five grasses (in descending order: Agropyron trichophorum, Stipa viridula, A cristatum, Elymus junceus, and A dasystachyum) were over 100 gm/m^2, those of four other species (A inerme, A smithii, A riparium and A trachycaulum) were in the 50-100 gm/m^2 range, Bouteloua gracilis' was 26 gm/m^2 and, because it did could not reproduce itself, wheat had no standing crop. Differences in standing crops across species on a given soil (or battery of soils) must be due to differences in plant durability (persistence) and/or efficiency of use of limited resources, especially water.

Across all species, standing crops were lower on salted plots (113 gm/m^2) than on unsalted plots (107 gm/m^2), but the difference was not significant (p=0.69). No species performed significantly better on salted than unsalted plots. While two thirds of the planted species produced less on salted plots, differences approached statistical significance for only Agropyron smithii (p=0.017), Stipa viridula (p= 0.06), and A riparium (p=0.12). The salinity effect on A smithii is surprising, since it is usually thought to be relatively salt tolerant (Richards 1969, Dewey 1960). Since both natural and added salt has mostly leached from surface soils (0-10 cm depth, Table 1) the salt effect must be due either to effects on initial establishment or to effects on the function of deep roots. At least for the rhizomatous Agropyrons, we cannot attribute the present low production to initial seedling establishment rates (because the grasses spread vigorously by rhizomes) and must attribute the salt effects observed to its effect on deep roots.

While six species had larger standing crops on clayey than sandy soils the differences approached statistical significance only for Agropyron smithii ($p=0.001$), A trachycaulum ($p=0.12$) and A riparium ($p=0.13$). Agropyron smithii often dominates clay-rich run-in sites in the high plains and one may associate its performance with the extra water. To the contrary, on our experimental site, A smithii is most successful on clayey soils despite the fact that they are, as explained above, probably droughtier. This phenomenon is consistent with the report that the drought tolerance of A smithii exceeds that of other grasses of the region, including Bouteloua gracilis (Lichthardt and Weaver 1985).

Standing crops of two grasses (Elymus junceus $p=0.05$ and Bouteloua gracilis $p= 0.21$) are significantly greater on coarse than fine soils. While the Bouteloua response is weak, it is consistent with the field observation that, while Bouteloua may occupy rather sandy sites, it is often replaced on clayey soils by A smithii or Buchloe dactyloides. One asks whether the poor performance of Bouteloua gracilis on relatively clay-rich soils is due to a high requirement for oxygen or an inability to compete with plants which favor the clay-rich soils. We do not know whether E junceus occupies coarse soils in its Russian homeland.

FACTOR EFFECTS ON WEED INVASION. Plants invading the plots included shrubs (Artemisia cana, A frigida, and A tridentata-- all too rare to consider now, but increasing), perennial grasses (primarily from adjacent plots), a perennial forb (Sphaeralcea coccinia) and annuals (principally Salsola kali, Kochia scoparia, Bromus japonicus, and B tectorum). Annual invasion varied notably with texture, salinity, and the species planted.

Annuals were essentially absent from plots with fine-textured soils (1 ± 1 gm/m^2) and increased significantly ($p=0.0001$) on loamy (10 ± 3 gm/m^2) and sandy (26 ± 6 gm/m^2) soils. We initially hypothesized that surface gravel on coarser soils might provide safe sites for establishing seeds (Harper 1977), but we found that, while gravelly sites (coarse 1&2 and loam 3)tend to support larger annual crops than gravel-free sites (loam 1 and clays 1&3), two relatively gravelly sites (sand 3 and clay 2) were almost weed free (Table 1). We fall back to the hypothesis that weeds fail on fine soils due to drought caused by loss of water to runoff and evaporation.

Overall, biomasses of annuals did not differ between salted (12 gm/m^2) and unsalted (12 gm/m^2) plots.

Annuals were more prevalently associated with some species than others. Of the total standing crop, annuals provided over 25% on some plots (A trachycaulum, A inerme, Triticum aestivum), 10-15% on some plots (A riparium, Bouteloua gracilis, A smithii), 5-10% on some plots (A dasystachyum, A cristatum, and Stipa viridula), and less than 2% on plots dominated by Elymus angustus and E junceus.

The degree to which annuals grow with a planted species provides an index-- in addition to the productivity (gm/m^2 x yr) of the planted grass-- to the ability of the planted grass to capture the resources on a site for itself. Very efficient resource capture-- whether by allelopathy, early spring growth, or other mechanisms-- may be considered good (if it is excluding weeds) or bad (if the achievement of high diversities mandated by law are countermanded); on this basis we suggest extremely cautious planting of the exotic grasses Agropyron cristatum, Elymus angustus, and E junceus.

Acknowledgements

Material support for this work was provided by the Montana Department of State Lands (Reclamation Division), the Northern Energy Resource Company (Spring Creek Mine provided the study site and created the pads) and the authors. We also value the encouragement of S Regele (MDSL), M Humphris (NERCO), and F Amendola (NERCO).

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Table 2. Standing crop (gm/m^2) of all plants, Spring Creek Experiment, 1989.

The soils are listed in ascending order of their water holding capacities. Species names are listed in the footnote. Data from non-salted (n) and salted (s) plots appear in alternate rows.

species	AGCR	AGDA	AGIN	AGRI	AGSM	ATRA	ATRI	BOGR	ELAN	ELJU	STVI	TRAE
exotics	*						*		*	*		*
sandy 2n	148	205	115	171	124	44	71	212	565	125	242	22
s	211	121	162	110	177	202	121	131	220	119	17	3
3n	66	186	142	66	55	77	251	149	921	103	298	155
s	104	104	111	29	130	40	287	103	629	79	146	195
1n	181	55	94	76	34	71	53	150	246	176	118	22
s	184	83	79	208	112	20	191	148	114	83	177	108
loamy 1n	102	74	90	40	92	56	98	50	293	129	149	73
s	161	90	32	44	47	114	91	120	255	140	142	91
3n	100	142	198	91	104	171	272	107	228	56	190	52
s	159	115	301	63	97	71	187	178	342	274	181	135
2n	187	150	163	85	87	37	292	129	665	189	140	170
s	56	63	215	42	78	126	174	44	1173	175	131	83
clayey 3n	165	211	121	81	98	137	80	85	286	46	278	162
s	103	218	96	47	113	130	130	89	507	178	153	85
1n	167	54	121	62	109	71	101	81	399	70	63	196
s	179	60	100	55	58	284	118	30	676	83	72	41
2n	44	133	46	53	145	83	111	70	523	59	108	200
s	35	80	35	108	85	12	79	59	486	55	66	116

The names of the grass species planted, abbreviated the first two letters of genus and species epithets above, are Agropyron cristatum, A dasystachyum, A inerme, A riparium, A smithii, A trachycaulum, A trichophorum, Bouteloua gracilis, Elymus angustus, E junceus, Stipa viridula, and Triticum aestivum.

Table 3. Standing crop of planted grass (gm/m^2), Spring Creek Experiment 1989.

The soils are listed in ascending order of their water holding capacities. Names of the abbreviated species are listed in the footnote. Data from non-salted (n) and salted (s) plots appear in alternate rows.

species exotics	AGCR *	AGDA	AGIN	AGRI	AGSM	ATRA	ATRI *	BOGR	ELAN *	ELJU *	STVI	TRAE *
sandy 2n	148	169	-	31	30	-	-	9	466	119	216	-
s	127	83	-	25	38	-	99	39	194	119	-	-
3n	66	186	142	66	44	73	249	33	900	103	292	-
s	104	104	76	29	68	33	231	52	246	79	146	-
ln	171	55	-	70	33	-	13	41	193	176	111	-
s	100	77	-	29	37	1	62	14	88	83	3	-
loamy 1n	102	67	37	36	91	38	98	39	286	129	141	-
s	160	62	15	38	45	-	73	16	249	140	141	-
3n	100	124	88	91	86	-	272	58	197	87	185	-
s	159	113	91	34	10	-	179	38	342	274	157	-
2n	187	95	149	61	85	33	292	-	665	189	57	-
s	56	63	215	38	29	124	171	8	1173	175	41	-
clayey 3n	164	211	113	81	98	78	80	32	287	46	276	-
s	74	218	92	48	113	130	130	14	507	178	153	-
1n	167	54	121	60	109	67	101	1	398	70	32	-
s	179	59	97	54	57	279	118	15	676	83	69	-
2n	44	133	35	53	144	80	111	13	523	59	108	-
s	35	80	70	108	85	-	79	3	486	55	66	-

The names of the grass species planted, abbreviated the first two letters of genus and species epithets above, are Agropyron cristatum, A dasystachyum, A inerme, A riparium, A smithii, A trachycaulum, A trichophorum, Bouteloua gracilis, Elymus angustus, E junceus, Stipa viridula, and Triticum aestivum.

Table 4. Standing crop (gm/m^2) of annual plants, Spring Creek Experiment, 1989.

The soils are listed in ascending order of their water holding capacities. Species names are listed in the footnote. Data from non-salted (n) and salted (s) plots appear in alternate rows.

species	AGCR	AGDA	AGIN	AGRI	AGSM	ATRA	ATRI	BOGR	ELAN	ELJU	STVI	TRAE
exotics	*						*		*	*		*
sandy 2n	-	36	112	140	94	44	21	57	100	-	16	15
s	84	38	119	85	46	-	3	75	17	-	6	3
3n	-	-	-	-	-	-	-	-	-	-	-	3
s	-	-	35	-	14	-	-	17	-	-	-	-
ln	10	-	39	6	1	56	36	100	5	-	6	22
s	84	5	77	44	75	19	12	37	2	-	58	87
loamy 1n	-	7	2	4	1	16	-	8	7	-	8	18
s	1	28	10	6	2	16	15	5	6	-	1	68
3n	-	2	110	-	7	171	-	-	-	-	5	40
s	-	2	-	5	-	63	8	-	-	-	-	-
2n	-	55	-	24	1	4	-	-	-	-	-	-
s	-	-	-	-	2	2	3	-	-	-	-	-
clayey 3n	-	-	-	-	-	-	-	1	-	-	1	-
s	-	-	-	-	-	-	-	-	-	-	-	-
1n	-	-	-	-	-	4	-	-	-	-	-	-
s	-	1	1	1	1	5	-	7	-	-	3	-
2n	-	-	3	-	-	3	-	-	-	-	-	-
s	-	-	-	-	-	-	-	-	-	-	-	-

The names of the grass species planted, abbreviated the first two letters of genus and species epithets above, are Agropyron cristatum, A dasystachyum, A inerme, A riparium, A smithii, A trachycaulum, A trichophorum, Bouteloua gracilis, Elymus angustus, E junceus, Stipa viridula, and Triticum aestivum.

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

EVALUATION OF NATIVE SOILS, OVERBURDEN SUITABILITY, AND RECLAIMED MINESOILS AT GIBBONS CREEK LIGNITE MINE, TEXAS

R. A. Blanke[1] and J. K. Horbaczewski[2]

ABSTRACT

Geochemical studies at Gibbons Creek Lignite Mine in east-central Texas have been used to evaluate the pre-mining native soils, the post-mining reclaimed minesoils, and the pre-mining overburden. The pre-mining native soils provide a site-specific baseline against which the reclaimed minesoils can be compared in considerable detail. Data for the reclaimed minesoils are available on a 5.75-acre grid basis. Each grid square is evaluated separately in relation to the native soil baseline and, where necessary, appropriate remedial action is taken.

The detailed reclaimed minesoil data are also being used to re-evaluate the pre-mining overburden geochemical data. The retrospective comparisons are showing that geochemical spatial patterns of pH and pyritic sulfur content could be predicted, to some extent, from the overburden chemical data. In the case of regular side-casting of overburden by the dragline, a dilution factor, based on the ratio of oxidized to reduced overburden, can be applied for such predictions. This approach is being used to determine the most appropriate overburden handling procedures for successful reclamation.

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INTRODUCTION

The purpose of this paper is to examine some of the geochemical relationships among native soils, undisturbed overburden and reclaimed minesoils at Gibbons Creek Lignite Mine, Texas. This information is being used for assessing reclamation success, determining the requirements for remedial treatment of acid-forming materials, and developing overburden handling plans.

The Gibbons Creek Lignite Mine, is located in east-central Texas, approximately 15 miles east of Bryan-College Station on Highway 30 (Figure 1). The mine supplies approximately 3.4 million tons of lignite per year to the nearby 443 MW steam electric generating station. Both the mine and the power plant are owned by the Texas Municipal Power Agency (TMPA). Navasota Mining Company, a subsidiary of Morrison-Knudsen Company, Inc., operates the mine under a contract with TMPA.

Lignite is recovered from a number of seams of the Jackson Group in the Manning Formation of Eocene age. The seams dip at an angle of 1-2 degrees to the southeast, and are mined in predominantly dip-oriented pits to a maximum depth of approximately 120 feet. The lignite is uncovered by 75-cubic yard Bucyrus-Erie draglines, removed by Easi-Miners and transported to the power plant by 120-ton haul trucks and a conveyor belt system.

This paper will deal with data from the areas reclaimed as of the end of 1987. This includes approximately 635 acres in Mine Block B-1 and approximately 800 acres in Mine Block B-2 (Figure 2).

METHODOLOGY

In order to characterize the native soils and reclaimed spoil, detailed field sampling was conducted in the summer and fall of 1987.

Native soils were sampled over an area of 3360 acres which included Mine Blocks B-1 and B-2. Samples were taken by coring to a depth of 4 feet (the depth of cover required to meet regulatory criteria for reclaimed minesoils in Texas). A total of 149 cores was recovered from areas of proposed disturbance giving an average density of 1 core per 23 acres. Cores were located in soils that were representative of disturbance areas. Each core was subdivided into intervals corresponding to the principal soil horizons.

Reclaimed minesoil was sampled on the basis of grid squares measuring 500 feet by 500 feet, representing approximately 5.75 acres. Within each grid square, 4 cores were recovered to a depth of 4 feet. Each core was subdivided into 1-foot depth intervals which were then separately composited with the corresponding depth intervals from the other cores from the same grid square. Thus, for each grid square, 4 samples were eventually obtained - one for each depth interval.

FIGURE 1: LOCATION OF THE GIBBONS CREEK LIGNITE MINE

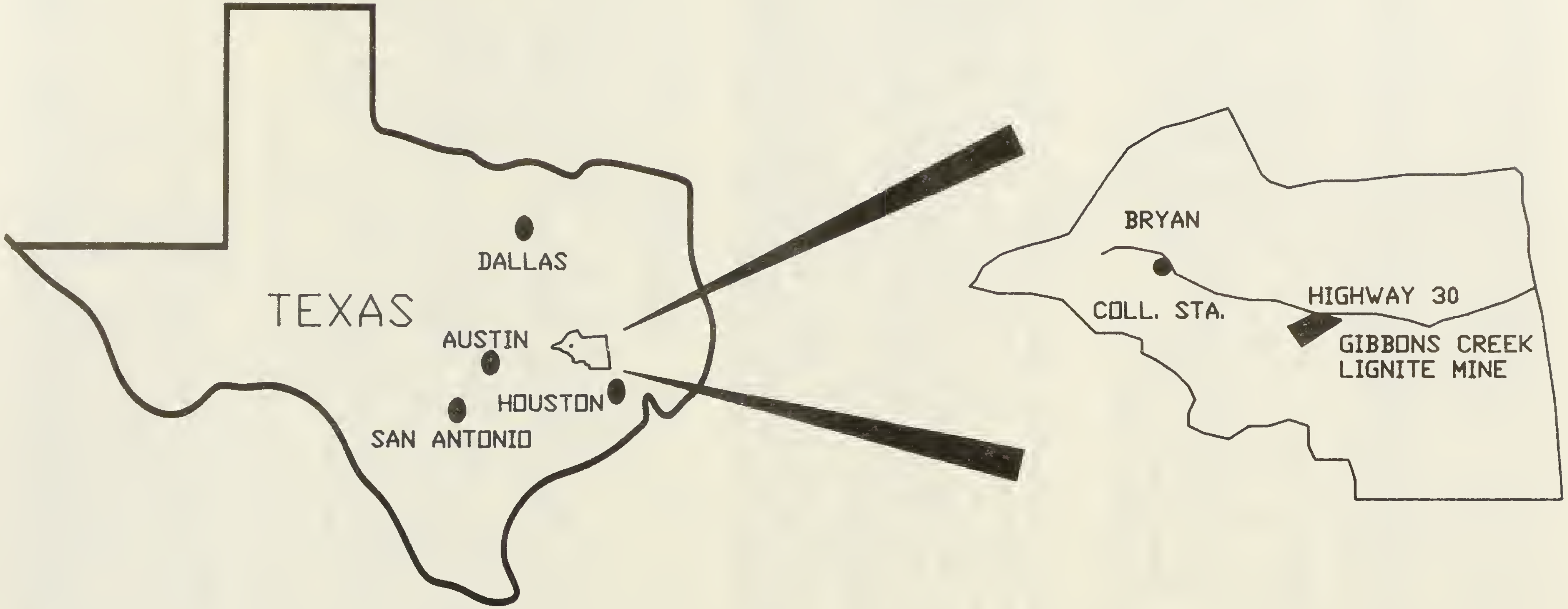
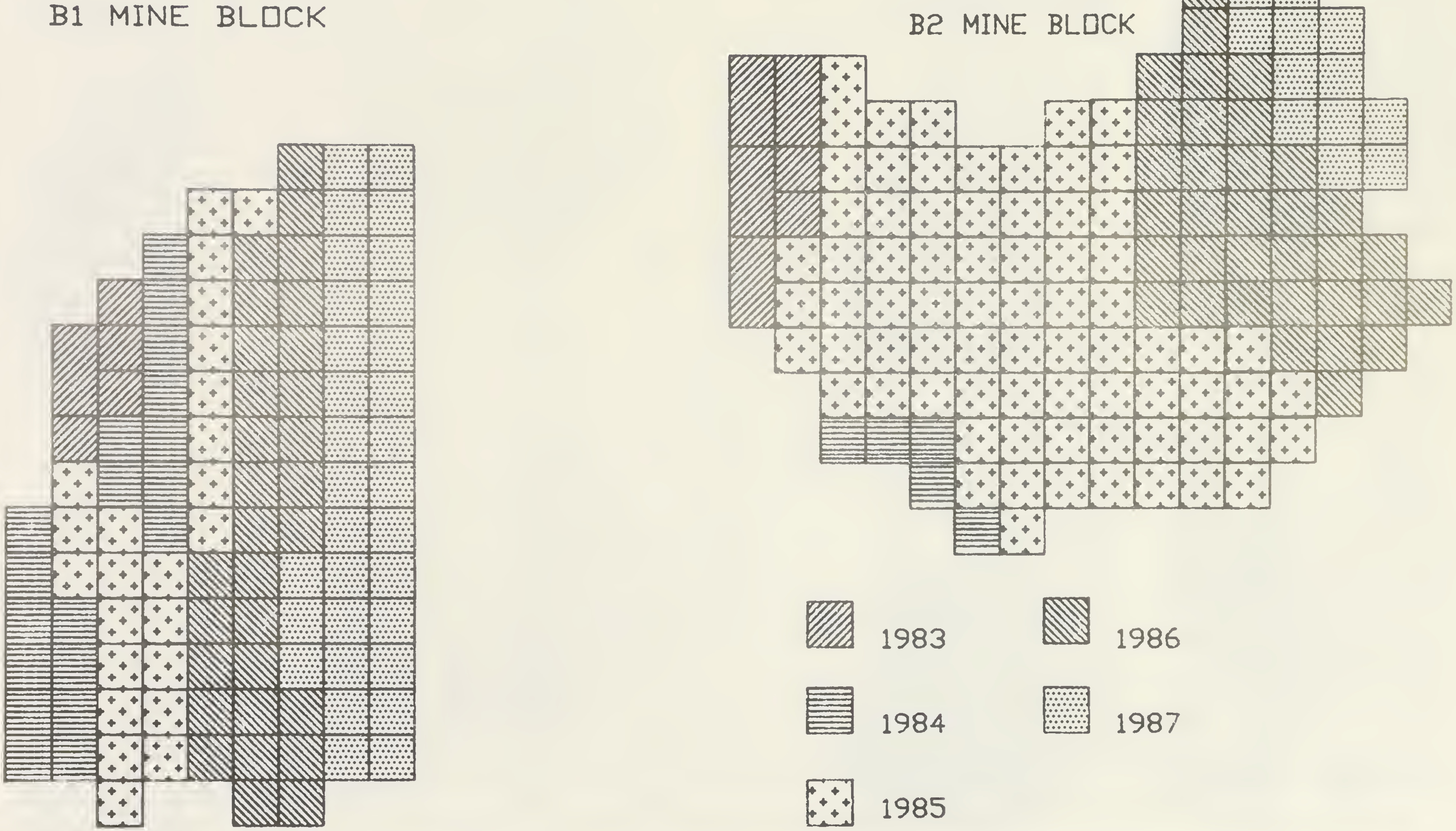


FIGURE 2: YEAR OF PERMANENT RECLAMATION



These intervals apply to areas reclaimed up until January 1985. After January 1985, native topsoil began to be replaced on the surface of the spoil. The depth intervals for sampling then became: 0-base of topsoil, and base of topsoil to 2 feet (rather than 0-1 foot, and 1-2 feet).

Pre-mining overburden geochemistry data were available from earlier drilling and coring programs conducted in the late 1970's and early 1980's. These data had been included in permit applications made to the Texas Railroad Commission (the state agency responsible for regulating the Texas Surface Mining and Reclamation Act) in the summer of 1985.

Laboratory procedures recommended by the Railroad Commission have changed over the years. The analytical procedures followed in the native soil and reclaimed spoil studies followed those formalized in the guidelines issued by the Railroad Commission on July 27, 1987. The procedures followed for the analysis of overburden cores prior to this time were determined in agreement with the Railroad Commission on a case-by-case basis. However, there are no significant differences between the procedures used for the overburden cores and the procedures used for the native soil and reclaimed spoil studies.

RESULTS AND DISCUSSION

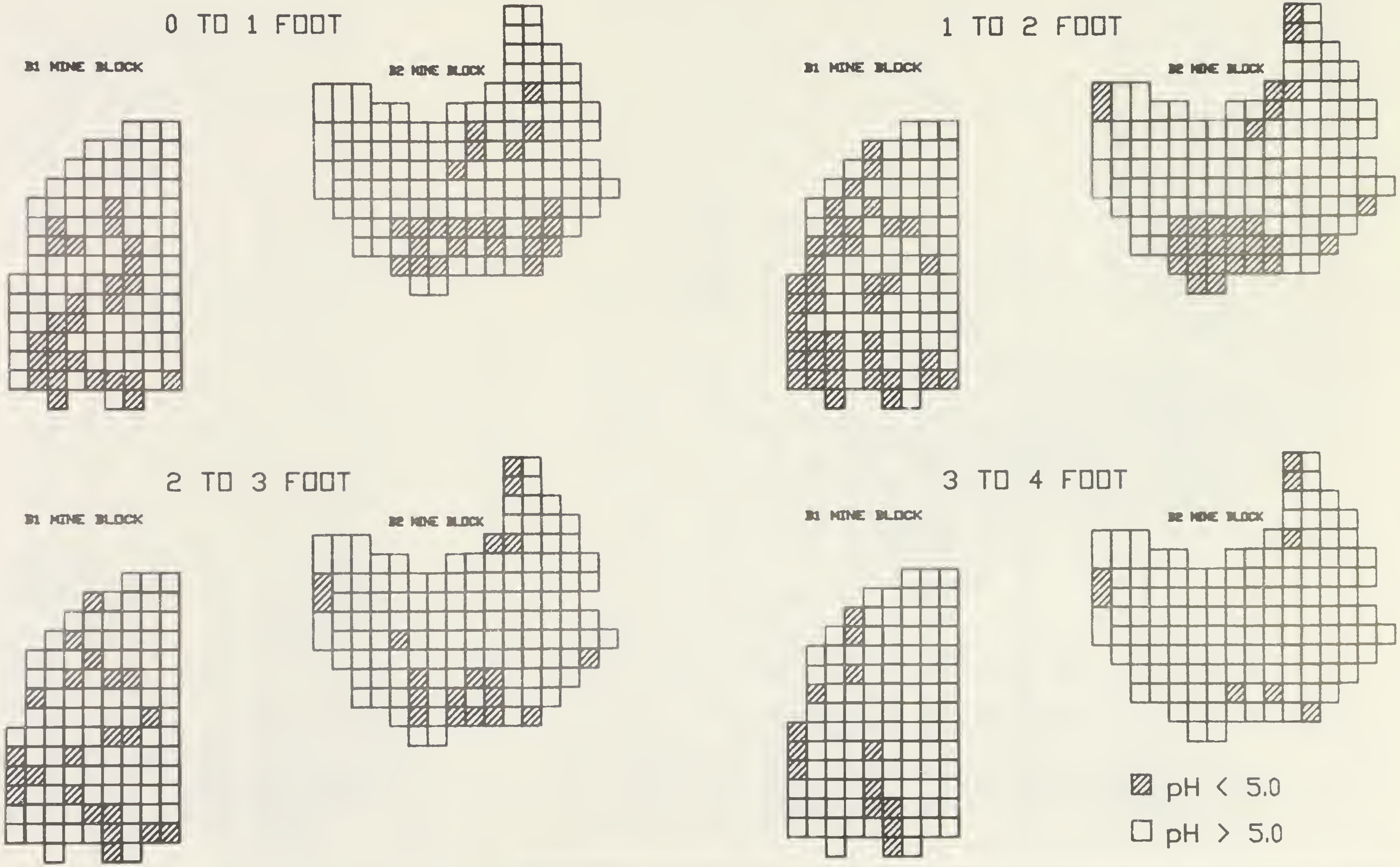
Evaluation of Reclaimed Minesoil Properties

pH Values

There are a number of trends that may be observed in the spatial distribution of pH values in the minesoil using the suitability criterion of pH 5.0 set by the Texas Railroad Commission (Figure 3).

The first trend concerns the distribution of low pH values by depth interval. The highest incidence of values lower than pH 5.0 occurs in the 1-2 foot interval, closely followed by the 0-1 foot interval. Field observations confirm that these are, indeed, the zones of most active oxidation processes. The predominant color of the spoil, as determined by Munsell soil color charts, changes from yellowish-brown (range of 10 YR-7.5 YR hues) in the upper 2 feet of spoil to greenish-gray (5 GY hues) in the lower 2 feet. Pyritic nodules, where encountered in the upper 2 feet, are typically very decomposed and partly replaced by gypsum, with aureolae of pale yellow jarosite; pyritic nodules in the lower 2 feet are less decomposed, with thinner or absent aureolae and fresh pyrite crystals in their interiors. Mottling and streaking of the spoil matrix with the characteristic yellows of jarosite and strong browns of hydrated iron oxides, is also more common in the upper 2 feet.

FIGURE 3: pH VALUES AT 1-FOOT INTERVALS TO 4-FOOT DEPTH



0 TO 1 FOOT

1 TO 2 FOOT

2 TO 3 FOOT

3 TO 4 FOOT

The second trend concerns the spatial distribution of low pH values within each depth interval. Both mine blocks show higher incidences of low pH values in their southern extensions which correspond to the down-dip portions of the mine blocks. The spatial distribution of low pH values is particularly well exhibited in Mine Block B-2. The distribution in Mine Block B-1 is less ordered. This is partly due to geological factors - specifically a sand channel running north-south though the middle of the area, and partly due to operational factors - irregular disturbance caused by the opening of a box cut in the southwest area and a mid-ramp haul road crossing the spoil from west to east.

Pyritic Sulfur Content

The spatial distribution, of pyritic sulfur (Figure 4) is based on the selection of the highest pyritic sulfur content encountered in any of the four depth intervals of a given 5.75-acre grid square. This selection process was used for two reasons: in the first place it eliminated depth intervals in which some of the pyrite had already been lost through oxidation and, in the second place, it served to register the maximum pyrite contents attained, in spite of dilution through mixing, in the dragline side-casting of the spoil. Areas of spoil with no pyritic sulfur in the top four feet are clearly demarcated from areas of spoil with contents of pyritic sulfur greater than 0.1% in the top four feet. In Mine Block B-2, the distinction is so clear that a coherent boundary line can be plotted. In Mine Block B-1, the distribution is less regular, probably as a result of the sand channel and the operational factors mentioned before. Nevertheless, there is an evident concentration of non-pyritic spoil in the up-dip portion of the mine block.

Evaluation of Native Soils

pH Values

The three most extensive soils in the mine blocks account for almost 80% of the area (Table 1). These three soils (as well as the less extensive Arol and Shiro soils) share the common feature of being upland soils of the claypan type. In general terms, these soils have three main layers or horizons: - the topsoil (A, or sometimes A and E horizons), the claypan (B horizon) and the parent material (C horizon). The horizons result from different soil processes and consequently have different chemical properties. They were, therefore, sampled separately. However, the data were subsequently weighted for 1-foot depth intervals, in accordance with Texas Railroad Commission requirements, for direct comparison with the corresponding depth intervals in the reclaimed minesoil. There are certain problems that result from the depth-weighting of native soil data, as will be discussed shortly.

FIGURE 4: AREAS WITH HIGH PYRITIC SULFUR VALUES

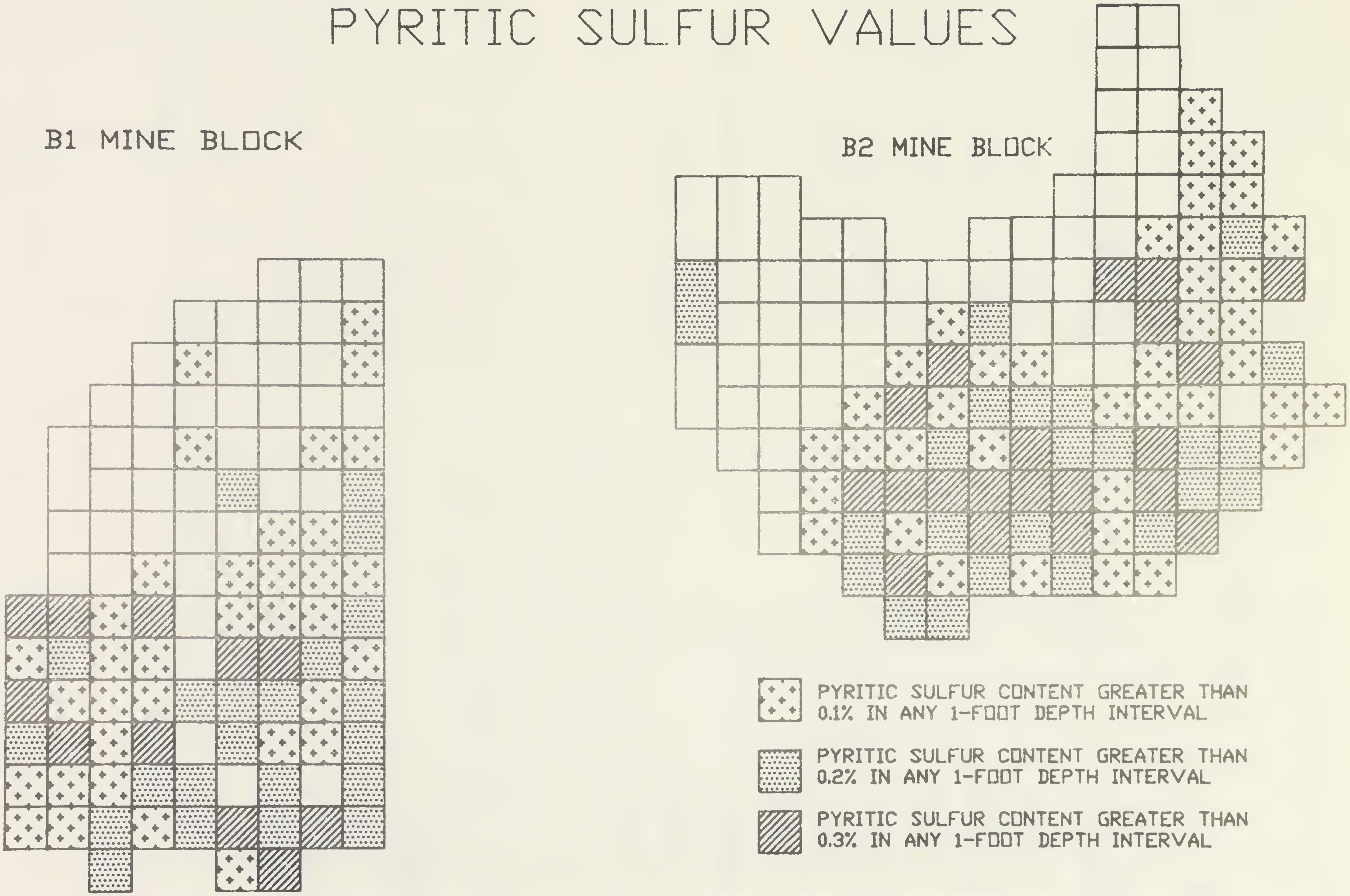

B1 MINE BLOCK
B2 MINE BLOCK
PYRITIC SULFUR CONTENT GREATER THAN 0.1% IN ANY 1-FOOT DEPTH INTERVAL
PYRITIC SULFUR CONTENT GREATER THAN 0.2% IN ANY 1-FOOT DEPTH INTERVAL
PYRITIC SULFUR CONTENT GREATER THAN 0.3% IN ANY 1-FOOT DEPTH INTERVAL

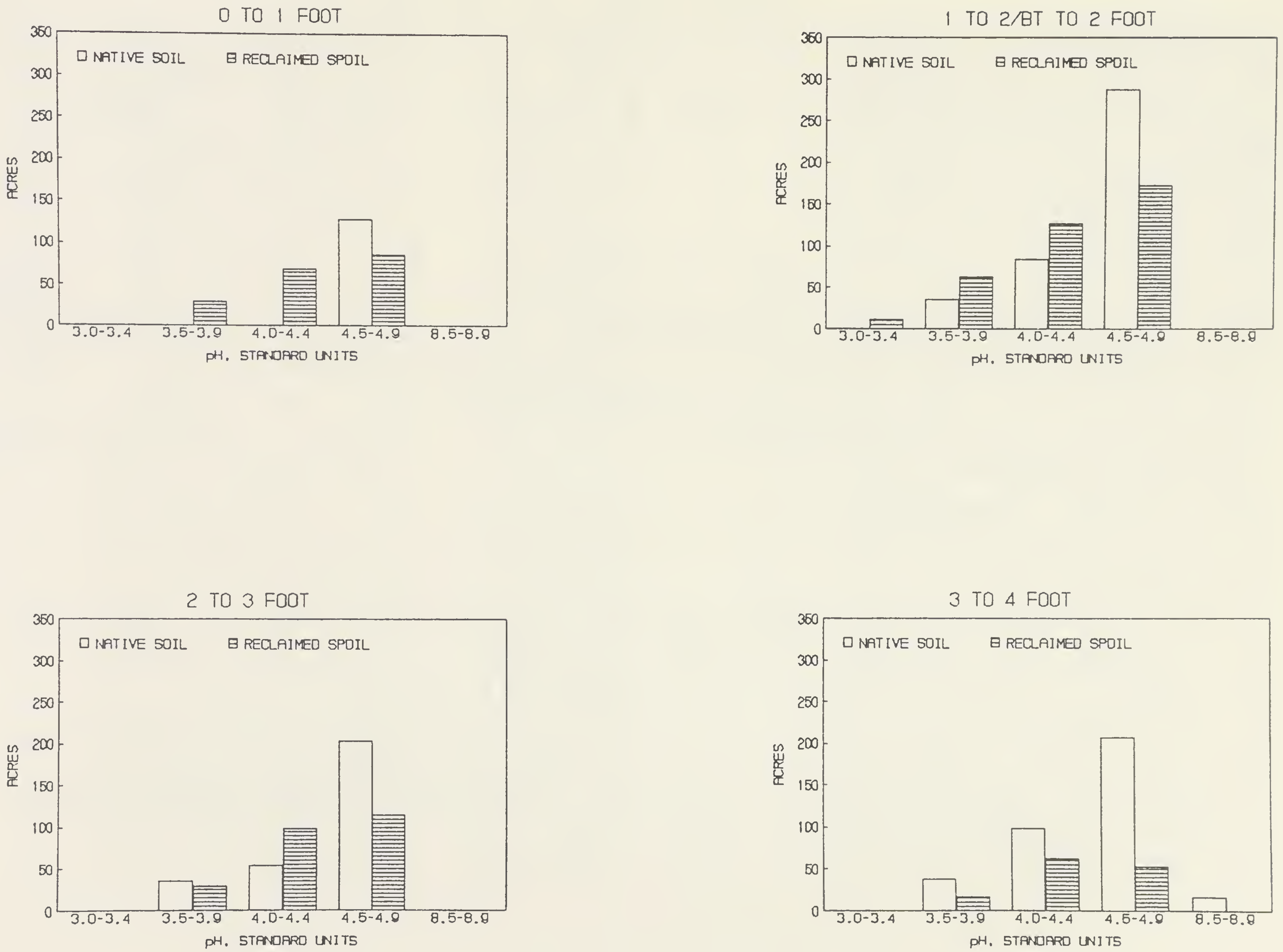
TABLE 1

DOMINANT NATIVE SOILS IN MINE BLOCKS B-1 AND B-2

Soil	Acres	%	Taxonomic Classification
Burlewash	988	45	Ultic Paleustalfs
Singleton	441	20	Aeric Albaqualfs
Elmina	293	13	Aquic Arenic Hapludalfs
Arol	118	5	Typic Albaqualfs
Shiro	103	5	Aquic Paleustalfs
Hatliff	103	5	Aquic Udifluvents
Padina	79	4	Grossarenic Paleustalfs
Nahatche	24	1	Aeric Fluvaquents
Others	32	2	
	2,181	100	

The procedure currently advocated by the Texas Railroad Commission for the evaluation of reclaimed minesoils against the native soil baseline is to construct frequency distributions for both. The distributions for pH values are based on increments of 0.5 pH units (e.g. pH 4.0-4.4, pH 4.5-4.9). The acreages of reclaimed minesoil for a given pH range are then compared against the acreages of native soil for the same 1-foot depth interval (Figure 5). Compliance with regulatory requirements is attained wherever acreages of reclaimed minesoils are within the acreages established by the native soils. Wherever the native soil acreages are exceeded, the Railroad Commission requires remedial action, such as liming or removal, to reduce the acreage down to the native soil baseline. Thus, remedial action becomes aimed at treating specific pH ranges in specific 1-foot depth intervals for particular acreages needed to balance the minesoil with the native soil.

FIGURE 5: COMPARISON OF pH VALUES IN RECLAIMED MINESOILS VERSUS NATIVE SOILS



In practice, the procedure used for determining which 5.75-acre grids needed remedial action was more complex: one reason was that pH was not the only criterion - exchangeable acidity and potential acidity had also to be taken into account; the second reason was that regardless of the procedure of balancing pre-mining chemistry against post-mining chemistry, there was still a need for liming of some grids in order to achieve satisfactory vegetative productivity. It should also be mentioned that there are serious theoretical problems associated with the depth-weighting of native soil properties by 1-foot depth intervals. The whole premise for soil classification and interpretation is that there are real differences among the soil horizons. In these claypan soils, the chemistry of the B horizon is significantly different to that of the A horizon. The depth-weighting procedure, however, arbitrarily blurs these differences by averaging the B horizon chemistry with the A horizon chemistry, particularly in the 0-1 foot and 1-2 foot depth intervals where the boundary between the two horizons most often occurs. In cases where the claypan is sufficiently acidic to inhibit plant root development, the averaging process obscures the existence of this limitation.

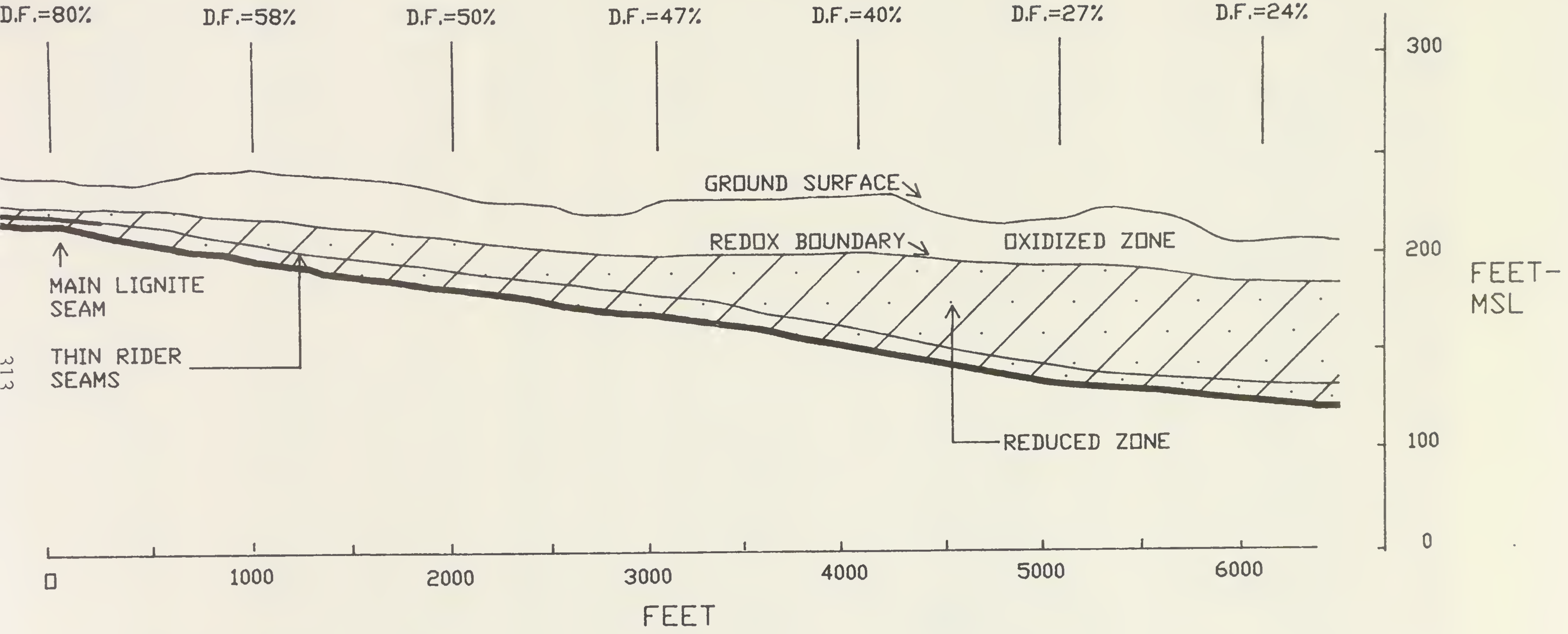
Evaluation of Overburden Suitability

Pyritic Sulfur Content

The availability of detailed minesoil chemistry data prompts the question of whether pre-mining overburden core data could be used for predictive purposes. This would appear to be particularly reasonable where regular dragline side-casting has been employed and where there is, therefore, relatively thorough mixing of the spoil material. As was seen in the pyritic sulfur contents of the spoil grids, there is evidence of a progressive increase in pyritic sulfur content in a down-dip direction.

A diagrammatic geological dip section across Mine Block B-2, based on pre-mining overburden cores, illustrates the general relations between geological strata, the oxidation-reduction (redox) boundary and the distribution of pyritic sulfur contents (Figure 6). These relations have been confirmed by subsequent highwall sampling programs performed in the course of mining. The redox boundary represents the depth to which oxidative processes have penetrated from the earth's surface. Typically, the boundary is very sharp, marking a color transition that occurs over a vertical distance of less than 1 centimeter. Above the redox boundary, the overburden has a yellowish-brown color and chemical analyses show no detectable pyrite; below the redox boundary, the overburden has a greenish-gray color and chemical analyses reveal the presence of pyrite which may range up to 0.5%, and occasionally even above that.

FIGURE 6: DIAGRAMMATIC GEOLOGICAL CROSS SECTION OF B2 MINE BLOCK



D.F. = DILUTION FACTOR (%)

$$= \frac{\text{THICKNESS OXIDIZED ZONE}}{\text{THICKNESS OXIDIZED + REDUCED ZONES}} \times 100$$

If the overburden is being moved by simple side-casting then the undesirable pyrite-bearing reduced material may be considered as being diluted to varying degrees by the non-pyritic oxidized material. The dilution factor (derived by dividing the thickness of the oxidized zone by the combined thickness of the oxidized and reduced zones) for the diagrammatic section of Mine Block B-2 shows a decrease from 100% at the subcrop of the coal seam (where there is virtually no reduced overburden) to 30% and less at the down-dip end. Thus, if it is assumed that the reduced zone has a uniform concentration of 0.3% pyritic sulfur, then a dilution factor of 50% would reduce it to 0.15% (0.3 x 0.50), and a dilution factor of 27% would reduce it to 0.22% (0.3 x 0.73) in the regraded spoil.

In reality, of course, the situation is more complex: - the reduced zone generally does not have a uniform concentration of pyritic sulfur; the thickness of the oxidized zone may be substantially altered in the course of preparing a dragline bench; and the dilution factor will be affected by variations in topography. Nevertheless, this model of gradually decreasing dilution appears to correspond well to the observed pyritic sulfur contents in the reclaimed minesoil, as described at the beginning of the paper.

CONCLUSIONS

The following conclusions may be drawn from the geochemical studies at Gibbons Creek Lignite Mine:

- The vertical distribution of pH values in reclaimed minesoil appears to be correlated with the degree of oxidation of pyritic material.

- Higher incidences of low pH conditions occur in down-dip parts of mine blocks.

- Progressively greater concentrations of pyritic sulfur in the reclaimed minesoils also occur in a down-dip direction.

- These spatial distributions of low pH and pyritic sulfur can be explained in terms of a dilution effect resulting from the mixing of oxidized overburden with reduced overburden in the course of regular dragline side-casting.

- Native soil baselines can be used for the evaluation of reclaimed minesoils but the procedure is complex and suffers from the defects imposed by arbitrary depth weightings which obscure the effects of natural soil horizonation.

Planning, Rehabilitation and Treatment of Disturbed Lands
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DETAILED CHARACTERIZATION OF DRILLING WASTES AND ASSESSMENT OF POTENTIAL LANDSPREADING RATES BY GREENHOUSE STUDIES IN ALBERTA, CANADA

T.M. Macyk[1]

ABSTRACT

In 1986 the Alberta Research Council initiated a project to provide a scientific basis for development of guidelines for drilling waste disposal. The three phases of the project involved detailed sampling, characterization and greenhouse studies relative to wastes obtained from the major oil and gas producing regions of Alberta. Three depths at each of five locations for both the liquid and solid phases of DAP, freshwater gel, invert, KCl and NaCl wastes were sampled. The liquid phases of all wastes were generally unsuitable for the uses of drinking, aquatic life, irrigation and livestock. The mean pH values of the solid phase materials ranged from about 8 to 10 and ANC and lime values indicated that all of the wastes had some potential as lime amendments. The mean oil contents ranged from 0.04 to 7.69% and the mean EC values ranged from 4.89 to 156 dS/m. Total elemental analysis data indicated that the mean values for most elements were within the range of values normally found in soils. The GC-MS spectra of the oil fractions extracted from the wastes indicated that organic compounds were concentrated in the neutral fraction. The rates of waste material added to soil in the greenhouse experiments were based on chloride content and liming potential. There were significant differences in yield relative to waste application rate for most treatments. Significant increases in pH, $CaCO_3$ equivalent, EC, SAR and Cl content resulted from addition of all waste types to soil.

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INTRODUCTION

Three basic drilling muds and variations thereof are used for oil and gas exploration in Alberta. These include the freshwater gel bentonite, the salt water systems which use sodium or potassium, and the oil invert mud.

The wastes produced from drilling operations contain many complex organic and inorganic compounds that are added at various stages of the drilling process. The materials that start out as a drilling mud before going down hole are usually quite altered once they enter a waste pit. Chemically and physically the muds can be altered by heat and pressure effects associated with drilling and by the addition of drill cuttings brought up with the mud system. The materials found in the waste pit can also be changed chemically and physically by other products that are purposely or inadvertently added to the pit.

Drilling wastes are currently disposed of by burying, trenching, squeezing, and spreading. Each of these disposal methods impacts the environment in different ways. For example, interactions of waste constituents with groundwater is much more likely to occur if wastes are trenched or buried as opposed to surface spread. The reverse is true for soils and plants. Review of the literature indicates that effects of disposal of drilling wastes on plants and soils varies with the type of waste, rate of application, and plant species.

Research associated with waste disposal from oil and gas drilling has received a considerable amount of attention recently, particularly research relative to the impact of land application of drilling wastes in western Canada.

OBJECTIVE

This research project was initiated to provide a scientific basis for development of guidelines for drilling-mud-solids-disposal that optimizes environmental safety and cost effectiveness by conducting research to identify environmental limitations of available disposal technology. The subobjectives were to:

1. characterize the drilling wastes resulting from different mud systems currently used in the Cold Lake, Foothills, and Grande Prairie/Peace River regions; and

2. assess the effect on soil properties and the changes in growth and trace element content of vegetation as a function of different concentrations of wastes mixed with soil.

MATERIALS AND METHODS

Sampling

The sampling program involved collection of wastes from sumps in the Cold Lake, Eastern Slopes (Foothills), and the Grande Prairie/Peace River regions of the province in 1986, 1987 and 1988 respectively.

Samples of the solid and liquid phases were obtained for most of the waste types and sites sampled. Wherever possible a total of five locations or horizontal positions with three depths at each position were sampled in both of the liquid and solid phases.

A variety of hand tools and backhoes were used for sampling the solid materials. A "discrete entity" sampler was designed and used for sampling the liquid materials. Boats or dinghies were used for transportation on the liquid sump cells. The bulk soil materials for use in the greenhouse pot trials were obtained from representative soils in the vicinity of the sumps. The upper 25 to 30 cm of the respective soil profiles were collected.

Analytical Procedures

The sump liquid samples were kept at 4°C upon receipt at the laboratory, centrifuged and filtered to remove the dispersed and colloidal materials and analysed for soluble ions, pH, and electrical conductivity soon after.

The sump solid samples were air dried and ground to pass through a 2 mm stainless steel sieve. Samples were analysed for water content, pH (water paste and 1:2 $CaCl_2$), carbon (total, inorganic, and organic), lime equivalence, acid neutralizing capacity, saturated paste extracts (pH, EC, soluble ions), cation exchange capacity, exchangeable cations, and particle size distribution. These samples were also analysed for extractable (DTPA) and total elemental contents and minerals were identified by X-ray diffraction. The oil contents of the solids were measured, and the oil fraction separated into acid, base and neutral fractions for analysis by gas chromatography mass spectroscopy (GC-MS).

The grass tissue samples were digested with a concentrated acid mixture and the solution concentration of Al, Fe, Zn, Mn, Ca, Mg, Na, K, Sr, P, Ba, Mo, B, S, Si, and As measured by ICP-AES and Cd and Pb by graphite furnace atomic absorption. Chloride content was determined by sodium nitrate extraction.

Greenhouse Pot Trial Methods

Soils and wastes from each of the three regions represented in the sampling and characterization program were utilized in the respective greenhouse experiments.

The pots used were 13 cm in diameter and accommodated 1 kg of soil and drilling waste mixture. Prior to planting the individual pots were watered to field capacity and fertilized on the basis of results from the available nutrient analysis. Fifty brome grass seeds were planted randomly in each pot and covered with 1 cm of soil/waste mixture. Moisture content was maintained at or near field capacity by watering on a pot weight basis twice a week. At two-week intervals the height of the grass was measured.

The plants were harvested 1 cm above the surface of the growth medium to minimize potential contamination. The fresh weight of each treatment was determined as soon as possible after clipping and dry matter weight was recorded following washing and drying of the plant material.

RESULTS AND DISCUSSION - CHARACTERIZATION

Liquid Phase Wastes

A total of 164 liquid phase samples were obtained from the various locations including 74 freshwater gel, 26 NaCl, 30 KCl, 25 invert, 6 DAP, and 3 water (no additives) samples. The invert wastes showed significant differences between locations for the smallest number of parameters measured whereas the freshwater gel wastes showed significant differences for the largest number of parameters measured.

The mean pH values ranged from a low of 7.26 for an invert waste to a high of 9.86 for an NaCl waste. The pH values for most of the wastes were in the upper range of values that are encountered in most natural and soil waters.

The mean EC values ranged from a low of 0.6 dS/m in one of the freshwater gel wastes to 32.0 dS/m in an NaCl waste. The latter value far exceeds the EC levels known to impede plant growth. The trace element contents of the liquid samples were generally low with many of the elements below the detection limit of the ICP-AES instrument.

The quality of the sump liquids and their suitability for various purposes were assessed by comparison with the maximum acceptable levels of inorganic constituents in the Canadian water quality guidelines (CCREM 1987). The liquids from all wastes were generally unsuitable for the uses of drinking, aquatic life, irrigation and livestock because of the levels of various constituents.

Solid Phase Wastes

A total of 163 solid phase samples were obtained from the various locations including 63 freshwater gel, 25 NaCl, 29 KCl, 20 invert, 20 DAP, and 6 water (no additives) samples.

The solid phase samples were analysed for several chemical and physical properties, soluble ions in saturated paste extracts, plant available trace elements (DTPA extractable), total elemental content, X-ray diffraction and oil content.

Chemical and Physical Properties

The mean pH values ranged from a low of 7.9 in an invert waste to a high value of 9.8 for a freshwater gel waste (Table 1). Significant differences in mean pH values between sampling locations (regions) for a specific waste occurred only for the invert waste.

Acid neutralizing capacity (ANC) mean values ranged from 3.2 to 24.7%. There were no significant differences in mean ANC values between regions for the individual waste types.

Table 1. Comparison of the mean values by waste and by location of the chemical and physical properties of the solid phase samples.

Waste	Location	N	pH (H_2O)	ANC* (%)	$CaCO_3$ (%)	Oil (%)
Freshwater	Cold Lake	15	9.73a**	12.1a	5.74ab	1.33a
Freshwater	Rocky Mountain	6	9.40a	5.29a	5.23ab	0.04a
Freshwater	Waterton	15	9.81a	7.47a	4.72ab	2.16a
Freshwater 1	Grande Prairie	15	9.19a	10.1a	8.56a	0.25a
Freshwater 2	Grande Prairie	8	8.59a	3.16a	2.26b	0.12a
Freshwater 3	Grande Prairie	4	8.95a	4.93a	4.57ab	0.14a
Invert	Rocky Mountain	9	7.93b	5.27a	4.27a	3.63b
Invert	Grande Prairie	11	9.79a	4.85a	4.10a	7.69a
KCl	Cold Lake	14	8.96a	8.45a	5.08b	1.63a
KCl	Waterton	15	8.36a	10.7a	8.89a	3.83a
NaCl	Cold Lake	15	9.49a	18.9a	9.48b	0.21b
NaCl	Slave Lake	10	8.85a	24.7a	19.2a	0.57a

* ANC - Acid Neutralizing Capacity.

** Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Oil content was generally highest in the invert and KCl wastes with a maximum mean value of 7.7% for one of invert samples.

The particle size distribution varied widely for the freshwater gel wastes which generally had the highest clay contents and the lowest sand contents of the major waste types characterized.

Saturated Paste Extract Data

Saturated paste extract data for the wastes indicate the magnitude of the soluble components in a saturated solution of these materials and can be used to assess the suitability of these materials for plant growth and the potential for trace element transport.

With the exception of a few values for the freshwater gel samples the mean EC values which ranged from 4.89 to 156 dS/m rendered all wastes unsuitable as a plant growth medium.

The soluble ions for the various wastes were dominated in general by the cations Na, K, and Ca, and the anions Cl and SO_4. Trace element levels in the waste were quite low with a few exceptions and for many of the elements below the detection limits of the ICP instrument.

Total Elemental Analysis

The total elemental analysis of the wastes is used to assess the potential for heavy metal and other trace element contamination.

The total element levels varied between waste type with none of the wastes containing consistently higher or lower levels of the individual elements. These values were compared to the values for total elemental content of soils (Lindsay 1979) to assess any potential hazard to a receiving soil from the addition of the wastes. All the mean values for the various elements were within the range of values normally found in soils except for Na, K, Mg, Zn, and Mo.

Oil Separation Characteristics

Oil was extracted from the solid wastes by methylene chloride soxhlet extraction, and the extract analysed for oil content. To facilitate the speciation of the methylene chloride extract, it was extracted further into acid, base and neutral fractions and each identified by gas chromatography mass spectroscopy (GC-MS).

The neutral fractions contained most of the organic compounds, so much so that a resolution of the individual compounds was not possible. To identify the compounds in the neutral fractions, further fractionation was completed and the results indicated a predominance of saturated hydrocarbons ($>$ 60%), but significant amounts of polyaromatic hydrocarbons were also detected.

RESULTS AND DISCUSSION - GREENHOUSE POT TRIALS

Trial Treatments

Three separate greenhouse experiments were conducted to coincide with the respective sampling and characterization activities. The rates of waste material added were based on chloride content and liming potential. Because of the relatively low chloride content of some of the freshwater gel and DAP wastes these materials were added on a weight proportion basis or on a liming rate basis.

Yield Measurements

The fresh and dry weights of the brome grass were determined for each of the treatments in the three individual experiments. For all waste types except the invert material, yield was enhanced at the lower waste application rates and then decreased with increased concentration. A comparison of the mean weights of the brome grass grown in the freshwater gel waste/soil mixtures is presented in Table 2.

Chemical Properties of the Waste/Soil Mixtures

Significant increases in pH and $CaCO_3$ equivalent resulted from the addition of all waste types to the respective soils. Significant increases in carbon resulted from the addition of invert, DAP, KCl and some of the freshwater gel wastes.

Saturated Paste Extract Data for the Waste/Soil Mixtures

Statistically significant increases in EC, SAR, and Cl content in the waste/soil mixtures occurred with increasing concentrations of all

Table 2. Comparison of the mean weights (g) of the brome grass grown in freshwater gel waste/soil mixtures.

Location	Cl Rate Kg/ha	N	Weight (g) Fresh	Weight (g) Dry
Cold Lake	0	3	4.50ab*	1.10a
Cold Lake	20	3	5.25a	2.03a
Cold Lake	40	3	4.74ab	1.98a
Cold Lake	80	3	3.54b	1.64a
Cold Lake	200	3	5.57a	1.65a
Cold Lake	400	3	5.72a	1.47a
Cold Lake	600	3	5.25a	1.28a
Cold Lake	800	3	4.74ab	1.22a
Cold Lake	1200	3	3.54b	1.03a
Waterton	0	3	7.34a	1.64a
Waterton	200	3	6.44a	1.24a
Waterton	400	3	7.18a	1.44a
Waterton	600	3	6.34ab	1.48a
Waterton	800	3	7.36a	1.64a
Waterton	1200	3	6.45a	1.36a
Waterton	2400	3	3.31b	0.49b
Rocky Mountain	0	3	6.54bc	1.82ab
Rocky Mountain	17	3	8.90a	2.55a
Rocky Mountain	25	3	7.06ab	2.01a
Rocky Mountain	51	3	4.55c	1.03b
Grande Prairie	0	3	8.74ab	2.34a
Grande Prairie	65	3	9.90a	2.69a
Grande Prairie	204	3	10.5a	2.60a
Grande Prairie	408	3	6.75b	1.65b
Grande Prairie	612	3	3.07c	0.73c

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

of the wastes from all sites. Table 3 provides data pertinent to these parameters for the freshwater gel waste/soil mixtures. The EC levels attained could be limiting to plant growth at some of the higher rates utilized for all wastes. Miller and Peseran (1980) suggested that many plants exhibit severe reductions in growth when the soil-paste extract conductivity reaches about 8 to 15 dS/m. The Alberta Soils Advisory Committee (1977, 1987) indicated that moderate limitations to plant growth occur at EC levels of 4 to 8 dS/m and that severe limitations occur at levels greater than 8 dS/m. Interpretations relative to the impact of waste application on the suitability of the waste/soil mixtures for plant growth as measured by EC could be based on these criteria.

Table 3. Comparison of the saturated paste extract data (mean values) for the freshwater gel waste/soil mixtures.

Location	Cl Rate Kg/ha	EC* (dS/m)	SAR**	pH	Cl (mg/L)
Cold Lake	0	0.16h***	1.0h	6.50c	7.95e
Cold Lake	20	0.77g	1.7gh	7.30b	9.05e
Cold Lake	40	1.06fg	2.6fg	7.57ab	13.3e
Cold Lake	80	1.53f	3.7f	7.70ab	28.6de
Cold Lake	200	2.91e	7.1e	7.92ab	102d
Cold Lake	400	4.65d	10.8d	7.97ab	260c
Cold Lake	600	6.00c	14.7c	8.05a	451b
Cold Lake	800	6.92b	18.1b	8.05a	520b
Cold Lake	1200	8.08a	22.7a	8.24a	645a
Waterton	0	0.69e	0.4g	6.50e	7.43f
Waterton	200	2.01d	6.1f	7.20d	111e
Waterton	400	3.14c	11.9e	7.47c	215d
Waterton	600	4.00bc	16.7d	7.55c	271c
Waterton	800	4.88ab	22.1c	7.68c	353b
Waterton	1200	4.79ab	30.6b	7.95b	379b
Waterton	2400	5.66a	56.7a	8.30a	483a
Rocky Mountain	0	0.11d	0.9d	5.48d	8.15b
Rocky Mountain	17	1.78c	8.3c	7.23c	9.90b
Rocky Mountain	25	3.23b	20.2b	7.83b	14.1b
Rocky Mountain	51	4.38a	45.2a	8.19a	41.6a
Grande Prairie	0	0.25e	0.6e	5.48d	8.84d
Grande Prairie	65	3.40d	6.6d	6.93c	21.5d
Grande Prairie	204	6.77c	18.2c	7.40b	109c
Grande Prairie	408	9.59b	32.9b	7.80ab	208b
Grande Prairie	612	11.3a	43.6a	8.12a	253a

* EC = Electrical Conductivity.
** SAR = Sodium Adsorption Ratio.
*** Treatment means in any one columnm not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Total Elemental Content of the Brome Grass

Statistical analysis of the tissue data indicated that significant differences in the elemental content of the brome grass grown in all types of waste/soil mixtures occurred. Levels of specific elements such as Al, Cl, Zn, Mn, and Ca found in the tissue grown in the waste/soil mixtures were significantly different for all waste types from all regions.

Chloride levels generally increased with increasing application rate of all wastes from all locations. The lowest rate of waste applied resulted in increased Cl levels in the tissue for all wastes and sites and in most cases the increase was statistically significant when compared to control values. The highest tissue chloride levels were associated with the invert, KCl and NaCl waste/soil mixtures.

For interpretation purposes the values obtained were compared to values reported in the literature (Chapman 1966) which represent a wide range of plants. Tissue boron and zinc levels were comparable to the respective intermediate range values reported by Chapman (1966).

LANDSPREADING OF SOLID WASTES

Criteria for Landspreading

Data obtained from the greenhouse studies showed that pH, EC, SAR, and Cl values were the most limiting properties relative to the impact of waste application on the suitability of waste/soil mixtures for plant growth. Oil content should also be included, however, more work would be required to separate the impact of oil from that of salts contained in invert wastes in terms of specifically assessing the impact of oil. The use of chloride addition as the criteria for determining KCl, NaCl and invert waste application rates appeared to be appropriate. Liming potential in conjunction with chloride content would likely be a more appropriate criterion for determination of application rates for the DAP and freshwater gel wastes.

Calculation of Application Rates

Depending upon the criteria selected for the application of drilling wastes potential rates that might be applied could be based partially on the criteria of the Alberta Soils Advisory Committee (1977, 1987). These criteria provide limits for various parameters relative to occurrence of no, slight, moderate, and severe limitations in regard to soil properties as they affect plant growth or crop production. It should be noted that trace element levels are not included in the above mentioned criteria. Comparison of the various parameters associated with the waste/soil mixtures following waste application with the criteria established provides an indication of the degree of limitation that might be expected.

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PIPELINE SOILS HANDLING IN ALBERTA:
Two-Lift vs. Three-Lift for Saline-Sodic Soils

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ABSTRACT

The Alberta Gas Transmission Division (AGTD) of NOVA Corporation of Alberta has installed more than 14,000 km of primarily natural gas pipeline since its inception in 1954. During AGTD's pipeline construction activities in the early 1980's the issue of changing soil handling techniques from its normal two-lift operation to a three-lift procedure for selected soils arose. In response to a lack of information about the impact of a three-lift procedure on soil quality, AGTD initiated a research project to evaluate its normal two-lift procedures alongside a three-lift procedure on the Standard Lateral. This paper presents some results of this pioneering research and includes a description of the area, study soils and construction techniques. The primary soil diagnostic variables selected for identification of soil quality changes in trench soils were electrical conductivity (EC), sodium adsorption ratio (SAR) and plant-available sulfate. Study results after five growing seasons reveal soil salinity and sodicity quality ratings exhibit little difference between two- and three-lift trench and off Right-of-Way soils. Also, after this time frame, any decrease in soil quality caused by pipeline construction was gone, i.e., soil impacts were short-lived irregardless whether constructed using the two- or three-lift procedure.

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INTRODUCTION

The preservation of agricultural soil quality is a specific goal of farmers, regulators, industry and the public in Alberta. Concern about the negative impact of pipeline construction on soil characteristics and crop yields has prompted various investigations e.g., **Hardy Associates (1983)**, and regulatory requirements for soil conservation. Experience with coal mining has also had an influence on soils handling for pipeline construction as attempts are made to transfer technology from one disturbance type to another. The practice of being able to strip and replace by soil horizon, or "lift", in coal mining has led some to advocate a more intensive use of this approach for pipeline construction. (A "lift" is the soil removed in one step and may be by soil horizon, e.g., Ap, or simply by depth, e.g., 0 to 15 cm).

NOVA Corporation of Alberta (NOVA) is a major Canadian energy company involved in natural gas transportation and marketing, petroleum, petrochemical manufacturing, consulting and research. The Alberta Gas Transmission Division (AGTD) of NOVA is concerned with natural gas system design, pipeline construction, research and facility operations throughout the province of Alberta. Since its inception in 1954, the AGTD has installed more than 14,000 km of natural gas pipeline and continues to operate, maintain and expand this system. Controversy about whether soils handling in areas of decreasing soil desirability with depth in the soil profile should involve the "normal" two-lift operation or whether another (third) lift should be utilized began in earnest in the early 1980's. Subsequently, in late summer of 1983, due to the lack of information about the impacts of 3-lift pipeline construction, the Alberta Gas Transmission Division (AGTD) of NOVA Corporation of Alberta commissioned Pedocan Land Evaluation Ltd. to conduct a research project to evaluate a 2-lift and 3-lift procedure. This paper presents some results of this pioneering research to evaluate a 3-lift soils handling procedure used in pipeline construction.

ISSUES/CONCERNS

Possible impacts of pipeline construction on agricultural land depend on soil characteristics, land use, construction practices, and weather conditions. The most commonly reported impacts are loss of topsoil or mixing of topsoil with subsoil; poor levelling or backfilling resulting in settling; presence of rocks and weeds; and reduced crop yields. Effects of pipeline construction on soil quality and crop yields are not always simple and easy to explain, however the value of good quality topsoil for a seedbed has been demonstrated many times. The physical and chemical properties that determine quality of topsoil and subsoil are also known, although the effects of altering natural soil dynamics are not well understood, especially in heterogeneous soil areas.

Recognition of the horizontally layered nature of soils and differentiation of quality by layer or horizon has resulted in development of soil handling techniques that attempt to maintain equivalent soil quality. Salvaging and replacing topsoil has become a standard practice on agricultural land in Alberta. The normal two-lift operation in pipeline construction **(Landsburg and Fedkenheuer, 1990)** handles the topsoil as the first lift (the Topsoil) and the remaining subsoil to trench depth as the second lift (the Mixed Subsoil).

Hardy Associates (1983) evaluated the impacts of pipelines on agricultural soils across Alberta. They reported a high incidence of topsoil mixing and burial, especially on old pipelines. This is not surprising with respect to the older lines as topsoil conservation in pipelining did not start to become an issue until the 1970's. Pipeline installation was found to have varying effects on growth of grain and forage crops depending on soil and climate. In a similar study in the Ottawa area, Shields (1979) documented yield reduction for several years due mainly to soil compaction and drainage problems resulting from construction during wet weather on clayey soils. In Saskatchewan deJong and Button (1973) did not find significant differences in yields over pipelines in Chernozemic soils except for one soil on which yields were higher. They found yields on Solonetzic soils were higher over older trenches than on the undisturbed fields, presumably due to a deep plowing effect. deJong (1980) attributed increased yields on pipeline trenches to increases in available plant nutrients and improved soil structure. Toogood (1974) reported significant increases in grain yields at 14 of 17 sites on pipeline trenches where topsoil and subsoil were mixed on Chernozemic and Solonetzic soils sampled one to ten years after construction. Naeth (1985) reported changes in soil parameters on Solonetzic soils under mixed prairie grasslands in southeastern Alberta as a result of pipeline construction, but these changes were generally not detrimental to plant growth. The factor she found of greatest importance, by far, in re-establishing native grassland, was the grazing system employed.

SOILS - GENERAL

The Standard Lateral is a 273 mm gas pipeline, 19 km in length, located in the Standard-Hussar area 75 km east of Calgary in Townships 24 and 25, Ranges 20 to 22, west of the 4th Meridian. The study area was located along a previously identified section of the route with saline-sodic lower subsoil layers. This pipeline crosses an undulating to rolling morainal plain, much of which has a clayey glaciolacustrine veneer. Dryland farming and oil and gas production are the primary land uses. Cereal grain and oilseed crops are produced in fields of 80 to 160 acres. The study areas are located within large fields, are unmarked and are farmed by the land operator as part of the fields. Sampling sites are located by surveying each fall.

The climate of the area is characteristic of the mixed-grass prairie in the Dark Brown soil zone. Mean annual precipitation at Standard is approximately 450 mm, with 320 mm falling from April to October **(Atmospheric Environment Services 1980)**. Rainfall is highly variable in total and in timing, and high moisture deficits frequently limit crop production in the area. The growing season extends from mid-April to early October with a mean frost-free period of 110 days (late May to mid-September).

The soils are predominantly Solonetzic Dark Brown Chernozemics (carbonated phase) and Dark Brown Solodized Solonetz developed in a clayey glaciolacustrine veneer overlying fine loamy till. The soils occur as intricate mixtures of Chernozemic and Solonetzic pedons over distances of a few metres, as is typical of Solonetzic soil landscapes **(Bowser et al. 1962)**. The depth to till is 60 to 100 cm. The test plots are located on a long northeast-facing slope of approximately three percent.

Topsoil horizons (Ap and Ae) are clay loam or loam textured; are non-saline and non-sodic; are slightly acidic to moderately alkaline; and are approximately 15 cm thick. B horizons (Bnt, Bntk) are clay or clay loam textured; usually have dense, columnar (Solonetzic) structure; may be carbonated to the surface or only in the bottom part; are non-saline and weakly to strongly sodic; are moderately alkaline; are non to weakly calcareous; and are 15 to 30 cm thick. The C horizons are in clay textured glaciolacustrine sediments or clay loam textured till that have high bulk density and low permeability. The C horizons vary considerably in morphology and chemistry from the 50 cm to 120 cm depth. The upper C horizons are often developed in relic Bnt horizons; are weakly saline; non-sodic; and strongly calcareous. Lower C horizons, and sometimes the entire C horizon, are weakly saline; moderately to strongly sodic; moderately alkaline; and often have abundant gypsum crystals.

CONSTRUCTION

The Standard Lateral was installed in August and September, 1983, using normal pipeline construction equipment. For both treatments topsoil (Ap) was stripped with a grader from approximately a 10 m wide portion of the 23 m wide right-of-way (RoW) to accommodate spoil storage and the trench. Ten to 15 cm of topsoil was windrowed to the edge of the RoW by two or three passes with the grader, which went deeper on the final pass in an attempt to salvage all of the topsoil (the first lift).

The two-lift trench was excavated to a trench depth of 140 cm in a single pass by a rotary ditcher. The excavated material, called Mixed Subsoil in this project, was stored next to the Topsoil windrow. Three-lift soil handling involved two passes with rotary ditchers. The first ditcher excavated to a depth of approximately 50 cm below original grade (depth was defined by the pre-construction soil survey) and moved the spoil (Midsoil) to the working side of the trench. The second ditcher excavated the remainder of the spoil (Lower Subsoil), and placed it next to the Topsoil windrow.

After the pipe was placed in the trench, backfilling of the Mixed Subsoil (two-lift operation) and of the Lower Subsoil (three-lift) was done with a power auger to within about 25 cm of the top of the trench. A Caterpiller Model 16 grader then compacted the fill with its tires, bladed in the remainder of the Mixed Subsoil and/or Lower Subsoil, and compacted it again. Replacement of these bottom lift materials resulted in the trench being completely filled in the three-lift operation and more than filled in the two-lift operation. In the three-lift operation the Midsoil was crowned over the trench and feathered to the sides with the grader. Topsoil was then replaced over the stripped area with a grader or dozer.

During final clean-up the entire RoW was worked with a vibra-shank cultivator with chisel teeth to a depth of 15 to 20 cm, and was then harrowed. Final clean-up followed closely behind construction.

METHODS

Pre-construction sampling in the open trench and off-RoW was conducted in fall, 1983. Soil profiles were sampled on a horizon basis and survey chainage to the trench sampling location was permanently recorded to assist in re-locating sampling points in following years. Five sites were sampled on the three-lift trench, the two-lift trench and control (field) soils off the RoW.

Duplicate cores were taken at each site with truck mounted coring equipment and then the two cores were composited by horizon to provide single samples of each horizon for chemical analysis. Set depth increments were used for sampling due to the considerable variability in horizon thickness and quality, and the lack of horizons in reconstructed trench soils. The selected depths correspond to mean plow depths and natural soil horizons as closely as possible.

Post-construction sampling in the backfilled trench began in fall, 1983. Samples were taken along the trench center line from the same spots where pre-construction samples were taken (Figure 1). Each year, sampling locations were established one m away from sampling locations established in the previous year. Four depth increments representing approximate horizon depths, were sampled as follows: 0-20 cm (Ap), 20-30 cm (B), 30-50 cm (lower B-upper C) and 50-80 cm (C). The 20 cm increment for the Ap horizon was chosen because of the deeper than normal tillage (20 cm deep cultivation with spikes) carried out during the clean-up phase.

The depth increments sampled in 1984 through 1988 were: 0-10 cm (Ap), 10-20 cm (upper B), 20-30 cm (lower B - upper C) and 30-50 cm (upper C). Depth of cultivation during these years was approximately 10 cm, therefore sample depths were changed to obtain 0 to 10 and 10 to 20 cm increments, in addition to the other depth intervals of 20 to 30 and 30 to 50 cm. The C horizon was not sampled below 50 cm to avoid any chance of contacting and damaging the pipe.

Soil analyses were conducted using procedures adopted by the Canada Soil Survey Committee **(McKeague, 1978)**. Sample depths and types of analysis were chosen to identify the diagnostic criteria for rating soil quality, with particular emphasis placed on those properties related to salinity and sodicity.

Complete randomization of factors was impossible in this study due to limitations of construction equipment, the fixed location of the pipeline and natural soil variability. **Entz (1989)** pointed out, in his review of the study's statistical design, that an analysis of variance is not appropriate considering the complications involved in addressing the fixed nature of most of the factors. He suggested that "Constructing confidence intervals for differences between means ... would provide quantitative results to work with". Therefore, to summarize the five years of data, the Students t-test for unpaired data was used to determine whether the difference between means was significant at $p \leq 0.05$. The following treatment comparisons by year and by depth were made: 1) control vs. two-lift; 2) control vs. three-lift; and 3) two-lift vs. three lift.

Results of sample analyses taken from the open trench face and off-RoW field locations confirm that a great deal of variability exists within the study area soils. It should be noted that this variability occurred despite the fact that samples were taken at locations where soils appeared similar (i.e. horizon morphology, texture, presence of lime and gypsum) to a professional pedologist. This confirms the findings of other laboratory studies **(Carter and Pearen 1985, Chang et al. 1986)** which have documented the variability inherent in salt-affected soils.

Diagnostic Soil Variables. The criteria used to rate soil quality were those proposed by the Soil Quality Criteria Subcommittee of the **Alberta Soils Advisory Committee (1987)**. These guidelines provide a subjective evaluation (Good, Fair, Poor, Unsuitable) of quality based on interpretation of physical and chemical properties of the soils (Table 1). The ratings are based on general predictions of soil

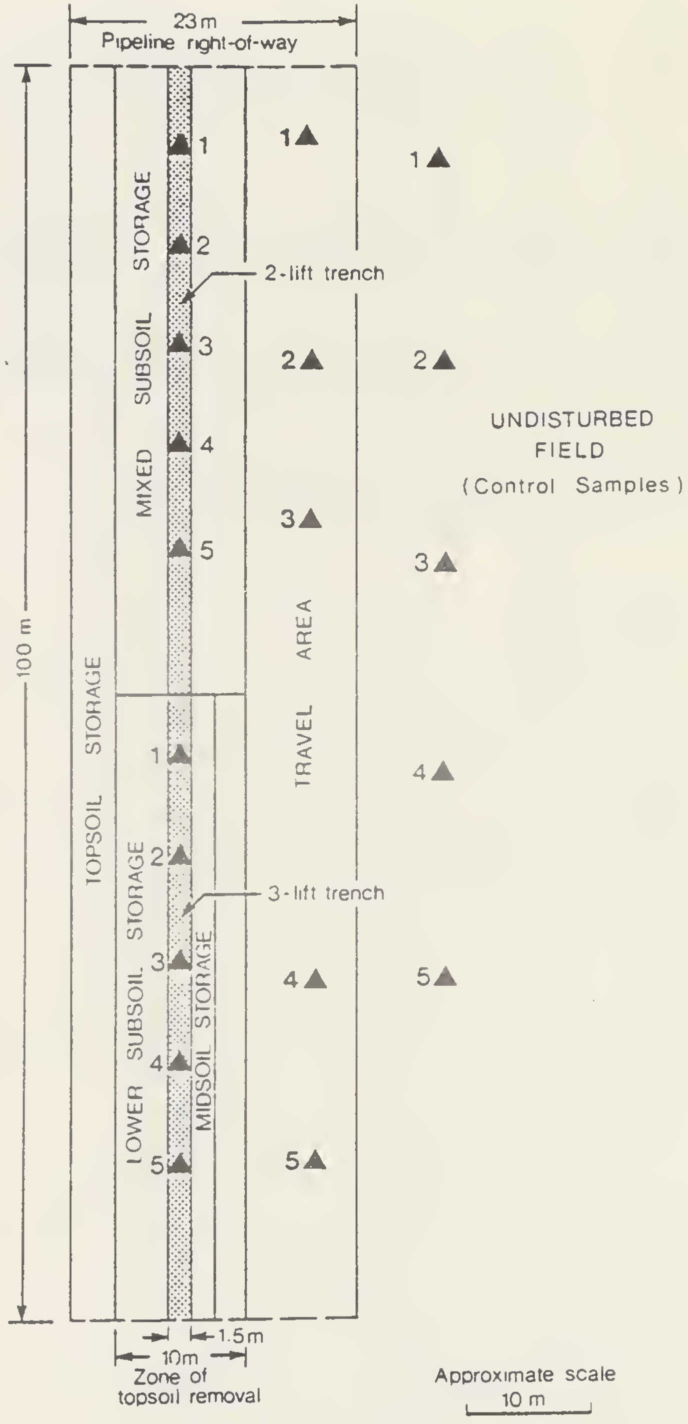

Figure 1. Outline of Continuous Treatment Section with Typical Sampling Locations.

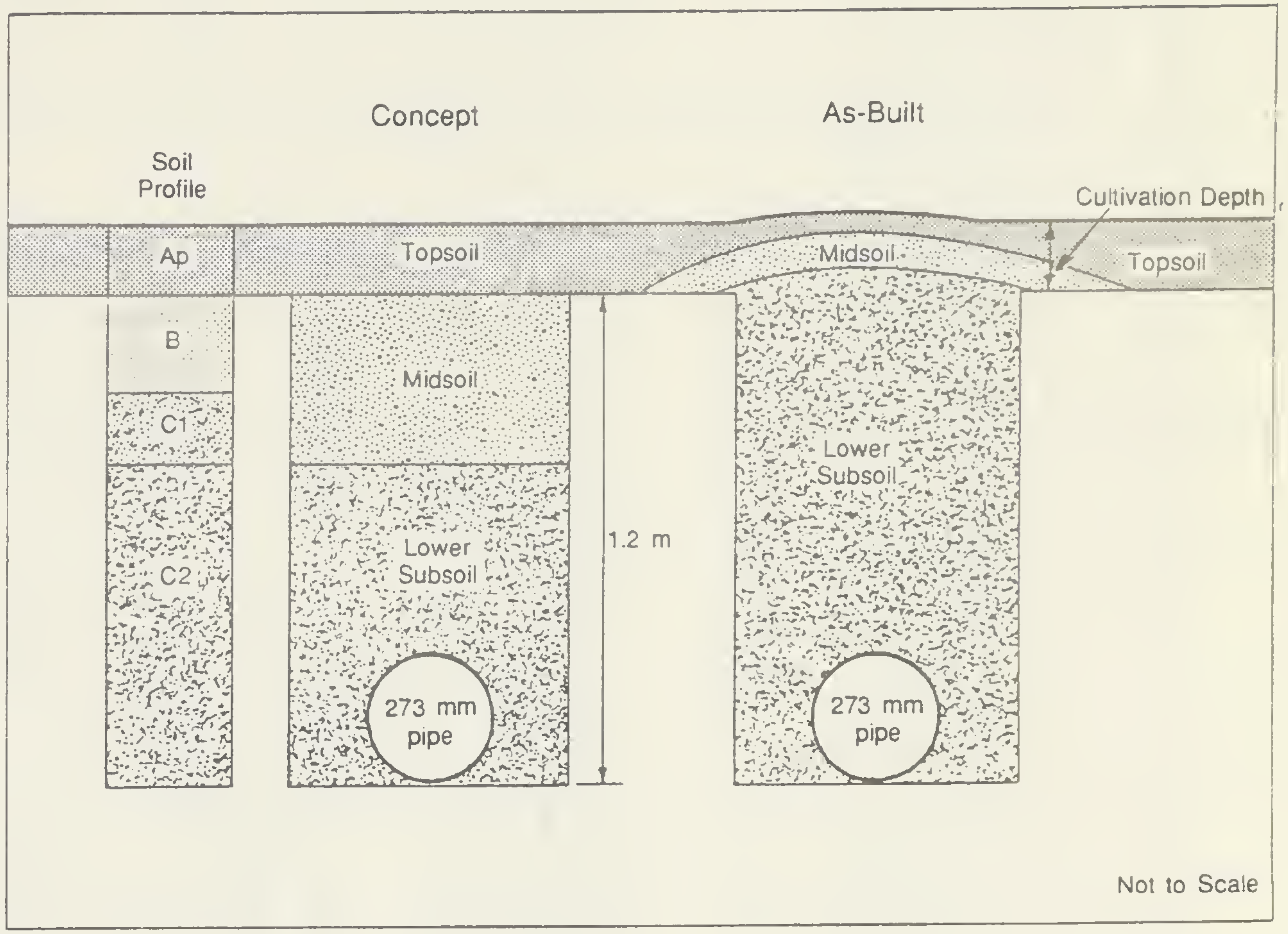

Figure 2. Conceptual and As-built Illustration of Three-lift Soil Handling.

Table 1. Criteria for evaluating suitability of topsoil and subsoil material for revegetation in the Plains Region[1].

Rating/Property	Good (G)		Fair (F)		Poor (P)		Unsuitable (U)	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Reaction (pH)	6.5-7.5	6.5-7.5	5.5-6.4 & 7.6-8.4	5.5-6.4 & 7.6-8.5	4.5-5.4 & 8.5-9.0	4.5-5.4 & 8.6-9.0	<4.5 & >9.0	<4.5 & >9.0
Salinity (EC) (dS/m)	<2	<3	2-4	3-5	4-8	5-10	>8	>10
Sodicity (SAR)	<4	<4	4-8	4-8	8-12	8-12	>12*	>12*
Saturation (%)	30-60	30-60	20-30, 60-80	20-30, 60-80	15-20 80-120	15-20 80-120	<15 & >120	<12 & >120
Stoniness Class	S0,S1		S2		S3,S4		S5	
Stone Content (% Vol.)	-	<3	-	3-25	-	25-50	-	>50
Texture	FSL,VFSL, L,SL,SiL	FSL,VFSL, L,SiL,SL	CL,SCL, SiCL	CL,SCL, SiCL	LS,SiC, C**,S,HC***	S,LS,SiC, C,HC	-	Bedrock
Moist Consistence	Very friable, Friable	Very friable, Friable	Loose	Loose, Firm	Firm, Very firm	Very firm	Extremely firm	Extremely firm
Organic Carbon (%)	>2	-	1-2	-	<1	-	-	-
CaCO3 Equivalent (%)	<2		2-20		20-70		>70	
Gypsum	The suitability criteria for sodicity (SAR) may be altered by the presence of high levels of either lime (CaCO3) or gypsum (CaSO4) in excess of other soluble salts.							

[1] Criteria established by Alberta Soils Advisory Committee (1987).

* Materials characterized by an SAR of 12 to 20 may be rated as Poor if texture is sandy loam or coarser and saturation % is less than 100.

** C - May be upgraded to Fair or Good in some arid areas.

*** HC - May be upgraded to Fair or Good in some arid areas.

performance and do not consider varying requirements or adaptability of individual plant species or special management input.

One of the major soil quality issues raised during planning of this pipeline project related to saline and sodic subsoil layers contaminating surface layers. Therefore, the primary diagnostic variables selected for identification of soil quality changes in trench soils were electrical conductivity (EC), sodium adsorption ratio (SAR) and plant-available sulfate (SO_4). These diagnostic variables are indicative of the quality of salt-affected soils and indicated sensitivity to treatments. Diagnostic variables of secondary value in identifying changes in soil quality which were also measured included saturation percentage, soluble cations (Ca, Mg, Na), calcium carbonate, soil pH and ammonium acetate-extractable cations.

RESULTS AND DISCUSSION

Soils Handling

Separation of Soil Horizons. There were no significant differences in any of the measured soil quality variables between the off-RoW Ap horizon and the excavated Topsoil pile or between the Mixed Subsoil pile and the Lower Subsoil pile (Table 2). The volume of each Subsoil pile was much greater than that of the Midsoil pile, and any dilution with poorer material in the Subsoil Mixed (if it occurred) was not detected. Midsoil EC, SAR and soluble Na levels were significantly lower than the values for the Lower Subsoil pile. Excavated Midsoil was of better quality than the Lower Subsoil due to lower salinity and sodicity. In the final analysis, a good job of soil separation was done.

Table 2. Comparison of key quality variables of off-RoW Ap horizon and excavated lift materials.

Soil Description	pH	EC (dS/m)	SAR	Soluble Na (meq/liter)	$CaCO_3$ (Wt%)
Ap horizon (off-RoW)	7.0a[1]	1.07a	1.0a	2.3a	0.32a
Topsoil pile	7.1a	0.88a	2.0a	3.9a	0.47a
Midsoil pile	8.1a	0.97a	5.4a	8.1a	3.40a
Lower Subsoil pile	8.0b	9.53b	15.8b	85.5b	3.40a
Mixed Subsoil pile	7.9a	9.77a	13.0a	77.9a	3.30a
Lower Subsoil pile	8.0a	9.53a	15.8a	85.5a	3.40a

[1] Within each comparison, means with different letters are significantly different at $p \leq 0.05$.

Soil Reconstruction. The three-lift procedure was successful in excavating good quality Midsoil, but the stratification of quality with depth was not evident in the replaced post-construction soil profile. Due to soil displacement by the 273 mm diameter pipe and bulking of the backfilled material, the Lower Subsoil completely filled the trench (Figure 2). The Midsoil had to be crowned over the trench and feathered to the sides for a width of approximately 2 m rather than being returned to the pre-construction location. Topsoil was replaced over the crowned trench and spoil storage areas to a depth of 10 to 15 cm, cultivated to a depth of approximately 20 cm, and harrowed. Mixing of Midsoil and Lower Subsoil occurred during replacement of the Midsoil; mixing of Topsoil and Midsoil occurred during Topsoil replacement; and mixing of all three materials occurred at the depth of cultivation. This mixing tended to negate the separation initially achieved with the three-lift excavation.

Soil Quality Monitoring

Salinity and Sodicity. Soils are considered to be saline when saturated extract EC values exceed 4 dS/m, but some sensitive crops will be affected at an EC of 2 dS/m (**Richards 1954**). Post-construction two-lift trench soils and three-lift trench soils tended to have higher mean EC values than control soils, however, the near surface sample layers (0 to 20 cm) usually had mean EC values of less than 2 dS/m (Table 3). The largest differences occurred in the first two to three years after pipeline construction, but

Table 3. Mean values of selected soil parameters by treatment for 1984, 1986 and 1988.

Soil Parameter[1]	Depth (cm)	Year:	1984			1986			1988		
		Treatment[2]:	C	2L	3L	C	2L	3L	C	2L	3L
EC	0-10		0.52	1.1*[3]	0.96*	0.86	0.84	0.92	1.4	2.5*	1.6[4]
(dS/m)	10-20		0.62	3.4*	1.5	1.0	1.5	1.5	0.92	1.4*	1.2
	20-30		0.84	6.4*	4.9*	1.4	3.5	4.4*	1.0	2.3	4.2*
	30-50		1.9	8.1*	7.0*	5.3	8.8	8.8	2.0	6.3*	6.7*
Avail. SO_4	0-10		10	23	39	20	17	26	16	17	20*
(ppm)	10-20		11	300	170	16	49	62	10	15	20*
	20-30		17	860*	830*	19	340	910*	11	19*	20*
SAR	0-10		1.2	3.7*	1.8	1.3	1.8	1.4	1.4	2.2	1.6
	10-20		2.6	6.6*	4.2	3.3	5.9	4.6	4.7	4.8	3.5
	20-30		4.5	9.2*	7.1	6.0	9.3	8.3	9.0	6.7	4.0
	30-50		11.0	12.0	14.0	8.2	12.0	15.0	9.7	8.6	9.9
SAT%	0-10		53	51	60*	53	50	59*	56	54	60
	10-20		55	51	57	55	50	61	58	54	59
	20-30		60	52	54	59	59	61	64	53	56
	30-50		60	54	61	58	57	65	68	56*	58
Soluble Na	0-10		1.52	7.02*	3.26*	2.46	3.26	2.78	3.30	6.88	4.44
(meq/l)	10-20		3.54	23.2*	8.74	5.50	10.1	9.50	6.12	8.94	6.78
	20-30		6.02	46.1*	32.5*	9.20	23.7*	26.1*	9.50	15.6	17.1*
	30-50		19.0	64.2*	61.6*	36.7	67.6	70.4	17.5	43.0*	44.9*
Soluble Ca	0-10		3.20	4.08	5.14	4.52	4.04	5.70	7.22	12.6*	11.1
(meq/l)	10-20		2.90	13.4	5.94	3.76	3.80	4.54	2.20	3.74	5.0*
	20-30		2.90	21.8*	24.8*	2.86	10.0	17.6	1.34	9.06	23.7*
	30-50		2.76	22.2*	19.8*	13.1	21.7	20.4	3.22	23.4*	22.2
Soluble Mg	0-10		1.46	2.90*	2.20	2.64	2.66	2.60	3.74	7.78*	4.16
(meq/l)	10-20		1.66	13.4	4.16	3.00	3.34	3.70	1.44	3.30*	2.38*
	20-30		2.04	26.8*	17.0*	2.88	11.9	15.7*	1.14	7.22	12.5*
	30-50		3.18	32.8*	23.2*	21.4	38.9	28.3	5.30	25.7*	18.0*

[1] EC = electrical conductivity, Avail. SO_4 = Available sulfate, SAR = sodium adsorption ratio, Soluble Na = soluble sodium, Soluble Ca = soluble calcium, Soluble Mg = soluble magnesium, SAT% = saturation percentage.

[2] C = Control, 2L = Two-lift, 3L = Three-lift.

[3] Within given year, area and depth mean is significantly different from control at $p \leq 0.05$.

[4] Within given year, area and depth underlined Three-lift trench mean significantly different from Two-lift trench mean at $p \leq 0.05$.

differences decreased with time. The surface layer of two-lift and three-lift soils showed no important differences until 1988 when small, but significant, differences were observed with two-lift soils having a higher mean EC than three-lift soils (2.5 vs. 1.6 dS/m). At the 20 to 30 cm sampling depth, however, the three-lift soil soils had a higher EC (4.2 vs. 2.3 dS/m). The net effect of the differences between the two- and three-lift soils after five years is negligible for soil quality.

The trends and relationships in EC values correlate well to available sulfate levels (Table 3). High levels of available sulfate were measured in both the two- and three-lift soils after construction, however, levels had dropped to very near control (off-RoW) levels by 1988. Available sulfate is a measure of primarily sodium sulfate salts which have much greater solubility and mobility than calcium sulfate (gypsum) or calcium carbonate (lime) salts **(Szabolcs 1989)**. The solubility of sodium sulfate is highly temperature dependent **(Szabolcs 1989)** and thus these salts are more soluble near the warmer soil surface than at depth. The sulfate levels in the trench soils decreased rapidly as expected while calcium carbonate levels remained essentially constant from 1984 through 1988 in the 0.8 to 8.7 percent range (Mean = 4.4%).

Soils are considered to be sodic when SAR levels exceed about 15 **(Richards 1954)**, however Alberta's suitability ratings of topsoil and subsoil change at an SAR of 4, 8 and 12 (Table 1). Sodicity levels, as indicated by mean SAR values, were low in all 0 to 10 and 10 to 20 cm samples (Table 3). The two 1984 cases of a statistical difference are not considered important in terms of affecting soil quality as they were gone by 1986. The two-lift soils had slightly higher SAR values in the 20 to 30 cm depth (9.2 vs. 7.1) in 1984 than did three-lift soils and this relative difference continued through 1988. In the 30 to 50 cm depth, three-lift soils had higher SAR values (14 vs. 12) in 1984 than did two-lift soils. This difference also carried through the 1988 growing season.

Other Analyses. The results of the saturation percentage analysis show the two-lift trench values to be slightly lower than those of the off-RoW field soils (Table 3). The saturation percentages for the three-lift soils are significantly higher (i.e., closer to dropping to a lower soil quality rating) in the surface 0 to 30 cm, even in 1988, than the two-lift soils. Soluble cations were found to support the trends and conclusions presented in the discussions of EC and SAR. Calcium carbonate levels increased with pipeline construction and tended to remain elevated, although generally not sufficiently to affect soil quality. The soil pH values were also elevated (0.1 to 1.0 units) and remained that way in 1988 likely due to the increased carbonate levels.

SUMMARY

As previously mentioned, criteria used to rate quality of soil are those proposed by the Soil Quality Subcommittee of the **Alberta Soils Advisory Committee (1987)**. Guidelines to define degrees of limitation within each criteria along with their numerical values are found in Table 1 for both topsoil and subsoil. Interpretation of physical and chemical properties of soils requires a subjective evaluation of quality (Good, Fair, Poor, Unsuitable). Alberta's soil quality ratings are based on general prediction of soil performance and do not account for varying requirements of individual plant species. Soil quality ratings for the soils of both the two- and three-lift trenches in this study field were reduced from Good to Fair or Fair to Poor for 1984 and 1986 when compared to the control (Table 4). Five years following pipeline construction (1988), soil salinity and sodicity quality ratings indicated there was little difference between the two- and three-lift trenches and the control soils. The combined quality rating shows no differences in the 0 to 10 cm soil depth for any of the years. The 10 to 50 cm depth exhibited some variation from the off-RoW soils in 1984 and 1986, but by 1988 the soils are similar. The important conclusion of this study is thus twofold in terms of salinity and sodicity: 1) after five growing seasons soil quality between the two- and three-lift soils exhibited little difference; and 2) any decrease in soil quality caused by pipeline construction was gone after five growing seasons; i.e. impacts were short-lived.

Table 4. Soil quality ratings for 1984, 1986 and 1988 based on EC, SAR and SAT percent.

Soil Parameter		Depth (cm)	Year:	1984			1986			1988		
			Treatment[1]:	C	2L	3L	C	2L	3L	C	2L	3L
EC	topsoil	0-10		G[2]	G	G	G	G	G	G	F	G
(dS/m)		10-20		G	F	G	G	G	G	G	G	G
	subsoil	20-30		G	P	F	G	F	F	G	G	F
		30-50		G	P	P	P	P	P	G	P	P
SAR	topsoil	0-10		G	G	G	G	G	G	G	G	G
		10-20		G	F	F	G	F	F	F	F	G
	subsoil	20-30		F	P	F	F	P	P	P	F	F
		30-50		P	U	U	P	U	U	P	P	P
SAT %	topsoil	0-10		G	G	G	G	G	G	G	G	G
		10-20		G	G	G	G	G	F	G	G	G
	subsoil	20-30		G	G	G	G	G	F	F	G	G
		30-50		G	G	F	G	G	F	F	G	G
Comb.	topsoil	0-10		G	G	G	G	G	G	G	G	G
Rating		10-20		G	F	G	G	G	F	G	G	G
	subsoil	20-30		G	P	F	G	F	F	F	G	F
		30-50		F	P	P	P	P	P	F	P	P

(Ratings based on: Soil Quality Criteria Relative to Disturbance and Reclamation (Alberta Soils Advisory Committee 1987).

[1] C = Control; 2L = Two-lift; 3L = Three-lift
[2] G = Good; F = Fair; P = Poor; U = Unsuitable

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ELECTRICAL TRANSMISSION LINES IN MONTANA: MITIGATION OF IMPACTS TO SOIL AND BIOLOGICAL RESOURCES

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ABSTRACT

In Montana, the routing and construction of large electrical transmission lines are regulated by the Montana Major Facility Siting Act. Under this act, impacts to resources are minimized through avoidance by routing, where possible, and by mitigating remaining impacts. Land disturbed by the construction of transmission lines considered in this paper ranges from 1681 acres for a 500-kV line across 156 miles of mountainous terrain to 11 acres for a 100-kV line across 27 miles of nearly level terrain. Line access accounts for most of the disturbance, especially when graded roads are built in mountainous terrain. Land disturbed by transmission line construction is susceptible to soil erosion and weed infestation. These problems are addressed through revegetation, erosion control, and herbicide application. Transmission lines can displace wildlife from critical habitats by disruptive construction activities or by improving human access to previously secure range. Wildlife impacts can be reduced by restricting construction periods and gating roads.

INTRODUCTION

Since 1973, the Montana Department of Natural Resources and Conservation (DNRC) has reviewed the potential environmental impacts of 24 transmission lines. The authors of this paper were responsible for addressing the biological, geological, and soils issues on nine of those lines (Figure 1). This paper examines the regulatory process, construction, soils and biological concerns, and solutions to those concerns on the nine lines. It is primarily based on information from environmental impact statements (EISs) and other documents contained in DNRC files. DNRC also considers economic, social, land use, and aesthetic impacts of transmission lines, but these impacts exceed the scope of this paper.

LEGAL BASIS FOR REGULATING TRANSMISSION LINES

The Montana Major Facility Siting Act (MFSA) is designed to give citizens a chance to participate in determining the need for large energy-related facilities such as major transmission lines and in determining where such facilities should be located. When an application for a new transmission line is received, DNRC prepares an EIS which examines the need for the facility and compares alternative routes. DNRC makes its recommendations concerning need, line location, and mitigating measures to the Board of Natural Resources and Conservation (Board). The Board considers these recommendations along with comments received at public meetings and in response to the EIS.

If the transmission line meets MFSA's standards for need and environmental compatibility, the Board grants a certificate. This certificate identifies a location for the transmission line and requires mitigating measures to reduce impacts.

Transmission line routes analyzed in an EIS are usually quite wide (up to 4 miles) to allow flexibility in locating the line to accommodate landowner and environmental concerns. When these concerns have been taken into consideration, the route is "fine tuned" into a "center-

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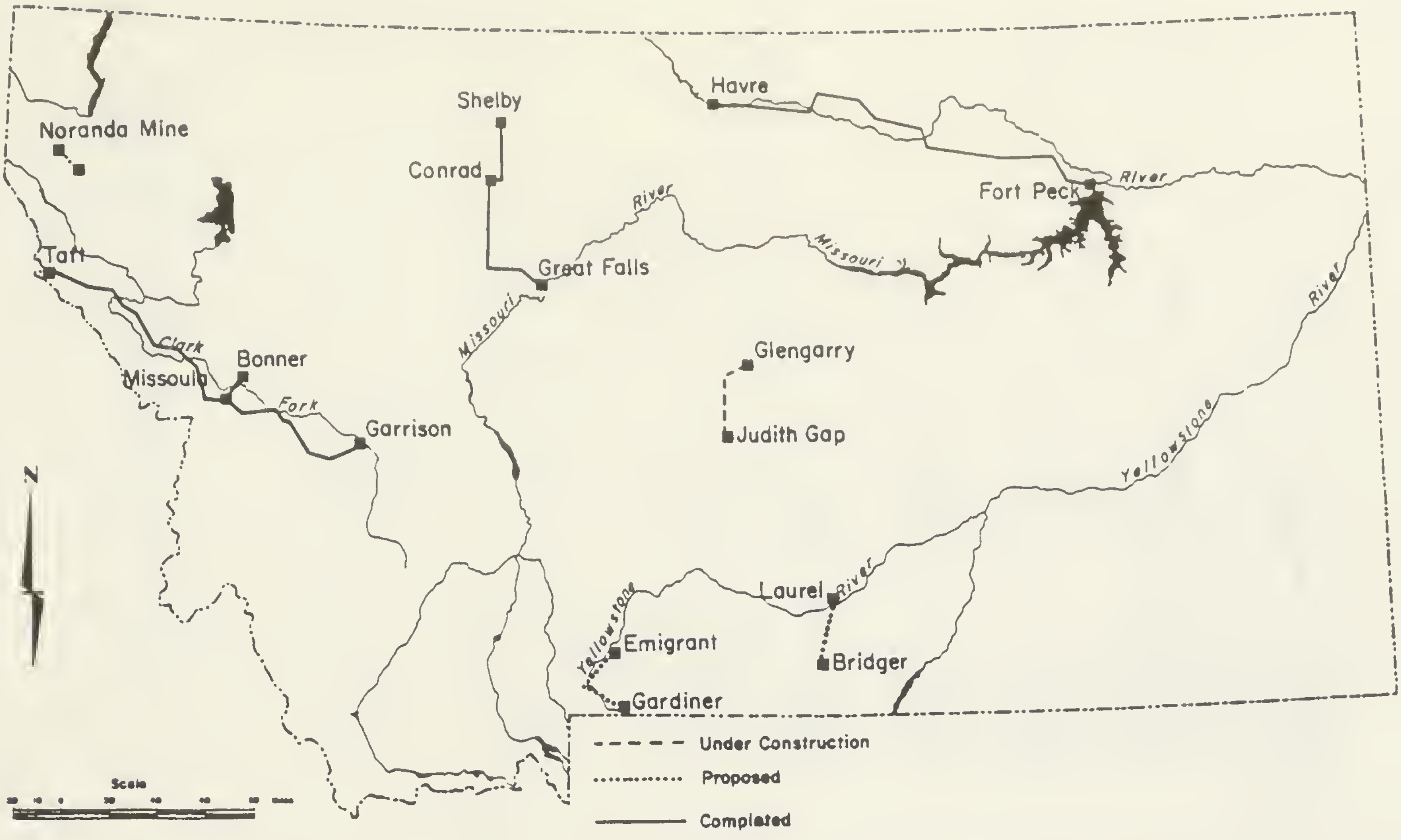

Figure 1. Locations of Montana transmission lines considered in this paper.

line." The centerline is selected through a second tier of analysis, the centerline process. This process considers the line's impacts within a 500-foot wide path contained in the previously approved route. The Board again accepts public comments and reviews a brief report by DNRC. In an order that approves a centerline, the Board may require bonds for construction and reclamation, specific mitigation, and monitoring by DNRC.

TRANSMISSION LINE CONSTRUCTION

The amount of disturbance associated with transmission line construction (Table 1) is influenced by the type and length of line, construction equipment, vegetation, and the terrain. A variety of structures have been used to support Montana transmission lines (Figure 2).

Before transmission line construction begins, the centerline is surveyed, structure locations staked, and trees cleared from the right-of-way. A minimum clearance specified by the National Electrical Safety Code must be maintained between the conducting wires and the ground or vegetation so that a flash-over does not occur and interrupt electrical service. Where trees are expected to approach the height of the conducting wires, a swath may be cleared along the length of the right-of-way. However, on the prairies of eastern Montana, little if any clearing is necessary. In the mountains, it is sometimes possible to span a valley to avoid clearing below the line.

Most ground disturbance is due to access roads or trails. This effect is especially pronounced when roads must be built through mountainous terrain (Table 1). On nearly level ground without woody vegetation, access roads for construction are usually not needed. In this situation, construction vehicles are driven along the right-of-way and a two-track access trail develops. On steeper terrain, existing roads are used as much as possible and short spur roads are graded to the structure sites. The type of equipment needed to build a structure and planned road use dictate the minimum width. Roads may be as narrow as 8 feet or as wide as 16 feet when an agency such as the U.S. Forest Service plans to use the roads for future timber sales.

Supporting structures are usually assembled on site and erected by crane (Figure 3); however, assembled structures can be flown in and erected by helicopter. Structures are set directly in holes except for the steel lattice structures (Figure 2) that are set on footings. Excavation for these footings disturbs considerably more area than does augering for direct setting (Table 1). Both excavation and augering require roads or trails to move heavy equipment to structure sites. After the structures are in place, a bulldozer, truck, or helicopter pulls a rope or cable (sock line) along the centerline. The sock line is then used to pull the conducting wires through the line of structures (Figure 3). Ground wires may be strung directly through the structures or with a sock line.

Table 1. Characteristics of selected transmission lines in Montana. Information from environmental impact statements, owner/sponsor applications, and personal communications from owner/sponsor representatives. Mileages and acreages are best estimates.

	Completed					Under construction	Construction pending		EIS in preparation
Line Name	Garrison-Taft	Ft.Peck-Havre	Great Falls-Conrad	Conrad-Shelby	Missoula-Bonner	Judith Gap-Glengarry	Laurel-Bridger	Emigrant-Gardiner	Noranda Mine
Owner/sponsor[1]	BPA	WAPA	WAPA	WAPA	MPC	MPC	MPC	MPC	Noranda Minerals Corp.
Voltage	500-kV	230-kV	230-kV	230-kV	161-kV	100-kV	100-kV	69-kV	230-kV
Length	156 mi.	180 mi.	74 mi.	30 mi.	15 mi.	35 mi.	27 mi.	27 mi.	16 mi.
Terrain crossed	mountains	prairie	prairie	prairie	mountains	prairie	prairie	mountain valley	mountains
ROW width	125'	150'	150'	125'	80'	40'	60'	40'	100'
Structure type	steel: lattice	wood: H-frame	steel: single pole	steel: single pole	wood: 75% H-frame 25% single pole	wood: 17% H-frame 83% single pole	wood: H-frame	wood: 5% H-frame 95% single pole	steel: single pole
Structures/mi.	4.0	7.5	6.5	5.0	7.0 H-frame 12.5 single pole	6.7 H-frame 11.7 single pole	6.6	10 H-frame 17.6 single pole	5.8
Acres disturbed/structure	0.38	0.15	0.15	0.15	.04 H-frame .02 single pole	.04 H-frame .02 single pole	.04	.04 H-frame .02 single pole	0.15
Miles of new access roads	280	2	0	1	5	0	0	0	7
Miles of access trail[2]	0	180	74	30	0	<1	<1	6	0
Total acres disturbed:	1681	438	192	66	42	17	11	23	60
by structures	234	203	73	23	4	9	7	10	14
by roads	1400	4	0	1	36	0	0	0	32
by trails	0	218	90	36	0	2	2	11	0
by substation(s)	8	6	27	5	0	4	0	0	2
by other[3]	39	7	3	1	2	2	2	2	12

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[1] Bonneville Power Administration (BPA) and Western Area Power Administration (WAPA) are divisions of the U.S. Dept. of Energy; MPC is the Montana Power Co.

[2] Exiting roads and trails minimized trail requirements for Judith Gap-Glengarry and Laurel-Bridger.

[3] Sites for structure assembly, line tensioning, and material storage. Noranda Mine figures include 11 acres for sock line pulling. Acreages of this disturbance type were not estimated for the Missoula-Bonner and Emigrant-Gardiner lines and were minimal for the other lines.

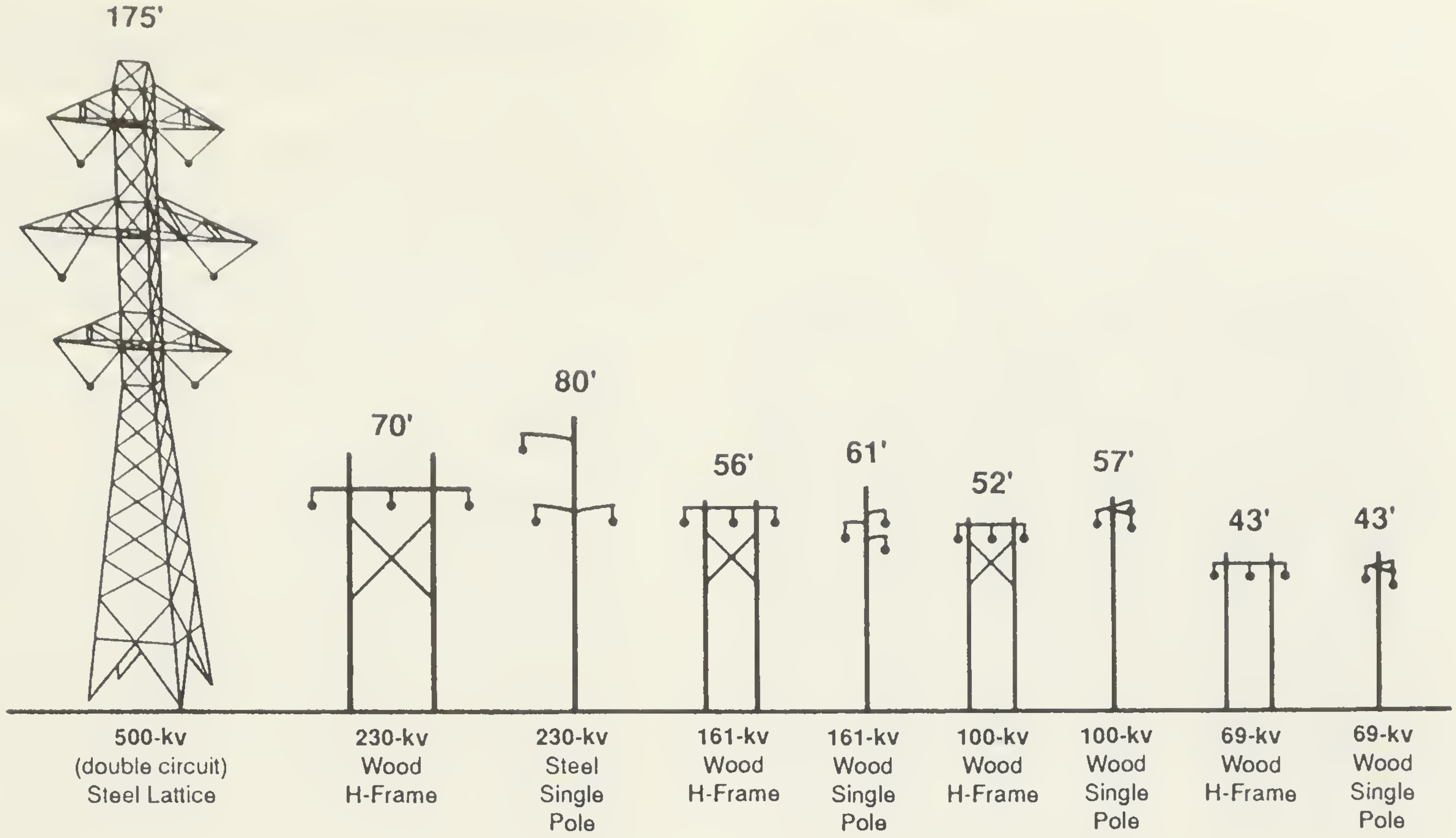

Figure 2. Supporting structures commonly used on Montana transmission lines. Guy wires are occasionally added for additional support.

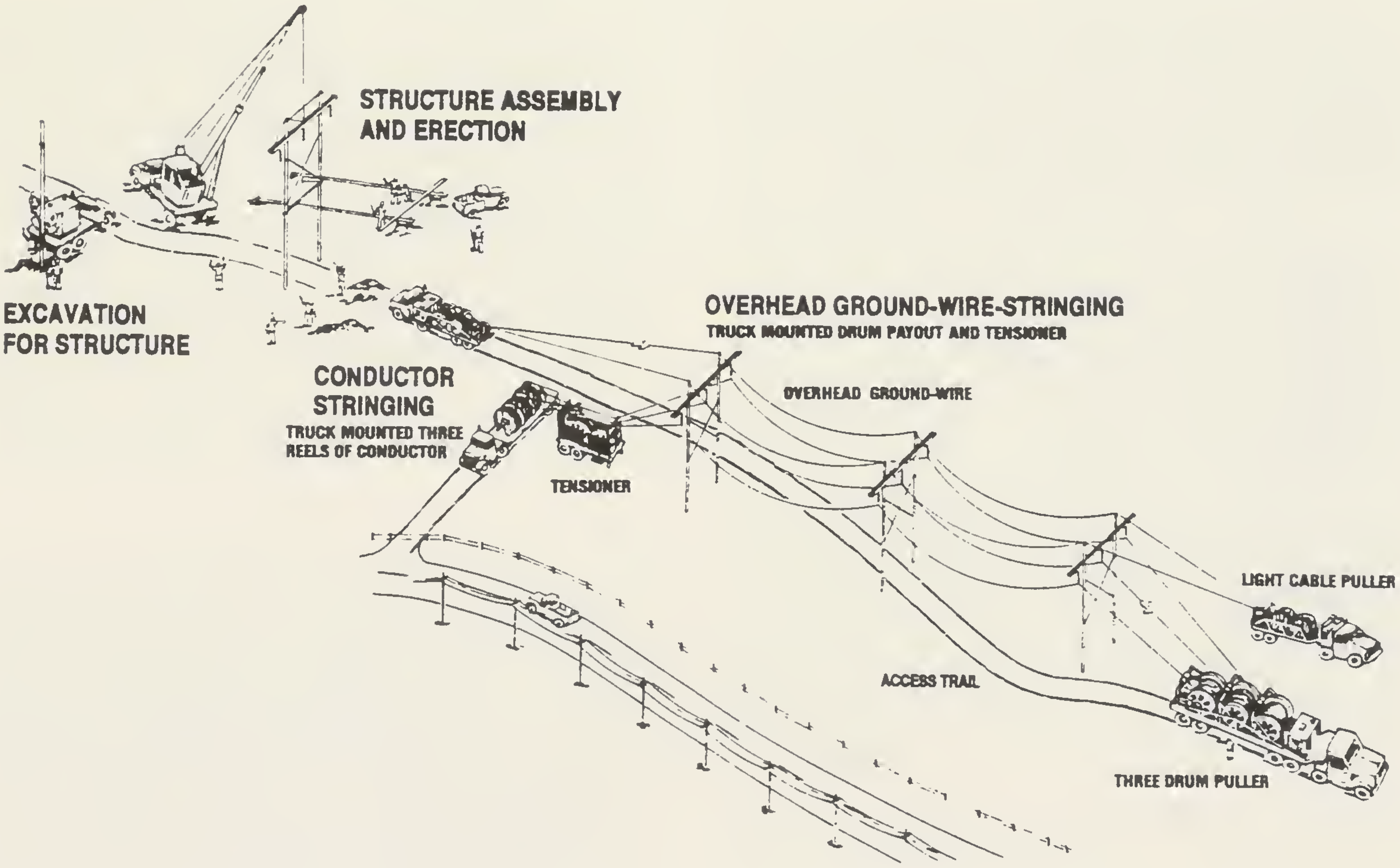
STRUCTURE ASSEMBLY AND ERECTION
EXCAVATION FOR STRUCTURE
OVERHEAD GROUND-WIRE-STRINGING
TRUCK MOUNTED DRUM PAYOUT AND TENSIONER
CONDUCTOR STRINGING
TRUCK MOUNTED THREE REELS OF CONDUCTOR
OVERHEAD GROUND-WIRE
TENSIONER
LIGHT CABLE PULLER
ACCESS TRAIL
THREE DRUM PULLER

Figure 3. Typical activities during transmission line construction. From U.S. DOE (1982).

ENVIRONMENTAL CONCERNS

Soils and Sediment

Soils can be affected by construction of transmission lines in several ways: through soil erosion, through removal and mixing of topsoil, by compaction and rutting, and by slope failure. Soil erosion can be accelerated either through removal of vegetation, which protects the soil particles from rain and wind, or by rutting and compaction, which can channel runoff through disturbed areas. Vegetation is removed by constructing access roads and leveling areas for erection of structures or line stringing sites. The amount of access road construction and land leveling depends on the final location of access roads, structures and stringing sites, and the type of construction equipment the contractor uses. Removing vegetation and grading may not be required on level or gently sloping ground or where an existing road can be used. In steep mountainous terrain, the probability of building a transmission line without constructing some roads is low. An access road system of 280 miles was required for the Garrison-Taft transmission line because large equipment was needed to construct this line and because nearly all of the 156-mile line was constructed in mountainous terrain (Table 1). Because the proposed 16-mile Noranda transmission line is also located in steep mountainous terrain, DNRC estimates that it will require about 6 to 7 miles of access roads even though there is an extensive system of logging access roads already in place. Terrain dictates structure location, and many structures on the proposed route for the Noranda line will not be located near an existing road. Graded roads are not used for access to lines built in gentle terrain. Construction vehicles travel cross country, creating two-track trails that disturb less land than graded roads.

Topsoil is removed and sometimes salvaged during construction of access roads. Salvaged topsoil can be spread on the road surface and small cut slopes during reclamation of the line. However, topsoil is often not spread on large cut slopes following construction, and these cut slopes can be difficult to revegetate and will be prone to erosion.

Most soil compaction is expected to result from the first two-to-three passes of heavy construction equipment. The degree of soil compaction on initial passes depends on soil moisture, texture, and amount of plant roots in soil; passes after the first few usually cause little additional compaction (Hatchell et al. 1970; Chancellor 1977). Soil compaction can result in decreased water infiltration and poorer soil aeration (Byrnes et al. 1981). Ontario Hydro (1977) notes that seedling emergence can be reduced by compaction. Rutting is caused by driving on fine-grained soils when they are wet. Rutting may channel water down bare soils and increase erosion and sedimentation.

Some soil and geological conditions may pose constraints which must be addressed when engineering the line or formulating mitigating measures. Roads may undercut stable slopes and cause landslides. Construction of the Garrison-Taft line caused several small landslides (rotational slumps) in the silts and clays of western Montana mountains. Slope failures may reduce the success of revegetation and prolong erosion problems.

Sediment that erodes from access roads and other disturbed sites can enter nearby streams. Excessive levels of sediment are known to depress populations of fish and aquatic insects and to damage spawning areas (EIFAC 1965; Gammon 1970; Phillips 1971). Of all transmission lines built or proposed in Montana, the Garrison-Taft line had the greatest potential to adversely affect aquatic life. DNRC identified 26 small trout streams that were crossed or paralleled by the line's access roads. A few of these streams contain fish species of special concern[1], such as bull trout (*Salvelinus confluentus*) and westslope cutthroat trout (*Salmo clarki lewisi*), thus increasing concern over potential impacts. The proposed line to the Noranda mine would cross or parallel aquatic habitat used by tailed frogs (*Ascaphus truei*), another species of special concern.

Stream crossings also can affect aquatic life. Fords, except across well-cobbled streambeds, agitate sediment and destroy localized areas of stream bottom habitats. Bridge building may contribute sediment, and disturbed soils around bridge foundations can erode into streams. Culverts, if "perched" above a stream's gradient, create small waterfalls that block upstream fish movements. High-velocity shallow water flowing through steeply angled small culverts also can prohibit upstream movements. These barriers prevent fish from returning to spawning grounds and summer-use areas. Like bridge disturbances, the disturbed soils surrounding culverts can be washed into streams.

Weeds

Transmission line construction disturbs soils and encourages weed growth. Construction vehicles can spread weeds by transporting weed seeds or other reproductive parts. Since a line's right-of-way typically crosses many different ownerships, different weed control efforts and infestation levels are encountered. Thus, weeds from an uncontrolled area can be introduced into a controlled area many miles away. Weed control along the right-of-way will be unsuccessful if weeds on surrounding lands are not also controlled.

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[1] Species of special concern are listed by the Montana Department of Fish, Wildlife and Parks (Flath 1984) or the Montana Natural Heritage Program. Generally, listed species are considered rare.

Many areas of western Montana are infested with spotted knapweed (*Centaurea maculosa*), a state-designated noxious weed. The Garrison-Taft line crosses many patches of spotted knapweed. Limiting the spread of knapweed is also a concern on the short Noranda mine and Missoula-Bonner lines.

Leafy spurge (*Euphorbia esula*), another designated noxious weed, affects far fewer acres than spotted knapweed but grows throughout Montana and is more difficult to eradicate. This weed was noted along routes for the Conrad-Shelby, Missoula-Bonner, Laurel-Bridger, and Judith Gap-Glengarry lines. The Judith Gap-Glengarry line is being built along an abandoned railroad right-of-way that also contains significant spotted knapweed infestations. Few weeds were found along the centerline for the proposed Emigrant-Gardiner line. However, the line would bisect a state-owned big game range, and even slight increases in weeds would reduce the value of this range. Other state designated weeds found along transmission line routes by DNRC include Canada thistle (*Cirsium arvense*) (several lines) and St. Johnswort (*Hypericum perforatum*) (Noranda mine).

Wildlife

The impacts of transmission lines on wildlife fall into three basic categories: (1) habitat alteration; (2) animal displacement; and (3) creation of physical hazards. Depending on the type and amount of habitat, alteration can be adverse, beneficial, or inconsequential. Displacement can be either short term or long term. Short-term displacement is caused by human activity on wildlife ranges during line construction; long-term displacement occurs when wildlife avoids the line and associated access roads. Transmission line wires also can pose a collision hazard to flying birds; however, this hazard is beyond the scope of this paper. Discussion of collision hazard can be found in Thompson (1978), Malcolm (1982), and Faanes (1983).

All transmission lines in Montana cross common types of wildlife habitats. White-tailed deer (*Odocoileus virginianus*) or mule deer (*Odocoileus hemionus*) habitats are crossed by all lines considered in this paper. Lines across eastern Montana often bisect pronghorn (*Antilocapra americana*) habitats, while lines through the mountainous west cross elk (*Cervus elaphus*) ranges. The quantities of habitats physically lost to transmission line construction (Table 1) are small when compared to the sizes of big game ranges. Thus, big game populations have not been noticeably affected by this loss. Furthermore, revegetation allows big game animals to use disturbed lands.

Right-of-way clearing through forests has the potential to increase forage plants for deer and elk. This may have occurred on the 824 acres of the Garrison-Taft right-of-way. The forage increase, however, was not expected to be great enough to increase populations (Interagency Technical Committee 1985)

Certain vegetation types in Montana are limited in extent, yet provide important wildlife habitat. For example, riparian vegetation grows only along watercourses, yet is heavily used by white-tailed deer, raptors, and songbirds. All lines considered in this paper cross watercourses and, thus, can remove deer cover and perching and nesting sites for birds. Aged stands of conifers, called old growth, also are scarce but important habitat for rare owls and woodpeckers. One of the alternative routes for the Noranda mine project locates the transmission line through two old growth stands. The shade from tall, dense conifers prevents an elk wallow from drying up along the Garrison-Taft line.

Transmission lines can depress populations if animals are displaced from critical areas, such as deer winter ranges, elk calving grounds, and elk security areas. Although these areas are large enough to withstand the physical habitat loss, construction activities or continued use of access roads can displace animals. Access roads cause the greatest impacts because they may be traveled as long as the transmission line stands.

The potential for deer and elk to be displaced from their winter ranges was noted along Emigrant-Gardiner and Noranda mine transmission line routes. The Garrison-Taft line was built through 25 elk winter ranges and one calving ground, creating a high potential for elk to be forced from these critical areas.

The 156-mile Garrison-Taft line required 280 miles of new access roads (Table 1). Many of these roads penetrate previously unroaded areas that had supplied security habitat for elk. Increased access was expected to force elk into marginal habitats, leading to an earlier and heavier harvest (DNRC 1983). This harvest, in time, could eventually cause more restrictive hunting regulations. Another long-term impact anticipated from the access roads was the opening to timber harvest of areas that otherwise would not have been logged for years (or perhaps never) because of marginal economics and lack of haul roads. Roads planned for the Noranda mine line raise similar concerns, although on a much smaller scale.

Like big game, populations of some bird species are tied to certain critical areas. Sage and sharp-tailed grouse perform reproductive displays and mate in areas known as leks. The Fort Peck-Havre line went through or near 17 of these leks.

RESPONSES TO ENVIRONMENTAL CONCERNS

Routing

Routing provides an opportunity to avoid adverse impacts to land use, social concerns, soils, vegetation, and wildlife. Steep terrain and important wildlife habitat can usually be avoided by judicious routing. However, social and land-use concerns often dictate that a new transmission line be located away from inhabited areas and areas that are farmed. Consequently, transmission lines are often built in rolling rangeland or in the mountains where impacts to soils, vegetation, and wildlife are often greater than they would be if built through more populated or farmed areas on gentle terrain. This situation occurred on major portions of six of the nine transmission lines discussed in this paper.

Standard Mitigations

Given the routing constraints described above, DNRC developed a standard set of mitigating measures designed to reduce the impacts from transmission line construction. These "Environmental Specifications" are adapted to each project during the EIS and centerline process. While these specifications keep evolving, their purpose remains the same: to produce good construction practices which consider the landowner, environmental impacts, economy, and engineering practice. The Environmental Specifications are designed to reduce ground disturbance when a line is constructed, ensure that disturbed areas are quickly reclaimed following construction, and provide a mechanism to address concerns as they come up during construction and reclamation (Table 2).

The Board order for a centerline usually designates a DNRC employee as the state's inspector to ensure that Environmental Specifications and other mitigations are implemented. On most projects, the inspector focuses on specific areas of concern identified in the EIS and centerline selection process and notes any other problems that develop. Inspections are made during actual construction of the line and reseeded areas are compared to adjacent, undisturbed areas 1 and 5 years after construction. The inspector recommends the release, retention, or forfeiture of construction and reclamation bonds. Revegetation is considered successful if after one complete growing season, vegetative cover is at least 30 percent of that on adjacent lands with similar slopes, aspects, and management activities. After five growing seasons the vegetative cover must be at least 90 percent of that on similar adjacent lands.

On the Fort Peck-Havre line, the inspector was on site after the first week of construction. He noted that the contractor was constructing more access roads than DNRC and the line's sponsor had agreed upon. The problem was corrected and similar problems were not encountered on the remaining 150 miles of the line.

On privately owned lines, the Board typically requires a construction bond and a reclamation bond. The construction bond is used to ensure that cleanup and recontouring of disturbed areas are completed soon after the transmission line is built. The reclamation bond is required to ensure that disturbed areas are adequately revegetated within 5 years following construction.

Reclamation and Erosion Control

Roads that are not necessary for line maintenance or desired by the landowner are reclaimed. Typically, the road surface is scarified or tilled to a depth of about 4 to 6 inches and seeded (Table 3). Gently sloping surfaces are drill or broadcast seeded and harrowed. Steep slopes, such as road cut-and-fill slopes, may be hydroseeded. Access trails and disturbed areas around structures structures also are reclaimed. Compacted soils may be ripped before seeding.

Table 2. Topics covered in Montana's Environmental Specifications for transmission line construction. The specifications are usually recommended by DNRC and required by the Board.

Equipment operation
Erosion & sediment control
Cleanup
Waste disposal
Monitoring
Maintenance inspections
Pesticides
Reclamation & revegetation plan
Culvert & bridge requirements
Roads to be closed and/or obliterated
Fire plan
Right-of-way clearing & site preparation
Right-of-way & road maintenance
Performance bond specifications
Specific standards waived or added by the Board
Environmentally sensitive areas
Variations in right-of-way width
Areas where construction timing restrictions apply
Areas where hydroseeding, fertilizing, or mulching is required
Watersheds and other areas where herbicides are prohibited
Right-of-way management

If a transmission line right-of-way intersects a steep drainage, erosion can be reduced in some instances by locating access trails off the right-of-way so that the road runs around the head of a drainage on flatter ground. Although the access trail is longer, the potential for erosion is greatly reduced because the amount of blading is considerably lower. On the Fort Peck-Havre line, access trails were frequently located outside the right-of-way.

Erosion control is accomplished primarily by revegetating disturbed areas. Water bars are usually installed in temporary access roads during final grading to funnel water away from the exposed road surface and prevent erosion. On permanent access roads that are not reclaimed, both water bars and culverts have been used to provide drainage. However, culverts can be difficult to maintain and have caused maintenance problems when used in remote areas.

After construction, the bridges and culverts intended for temporary use are removed and the streambanks recontoured and reseeded. However, most stream crossings used during construction are left in place if needed for maintenance.

Controlling erosion by revegetating disturbed areas and installing control structures reduces sediment levels in streams and protects aquatic life. Other control methods include curtailing construction during periods of soil saturation or spring runoff and maintaining buffer strips of undisturbed vegetation along streams.

The effectiveness of sediment control was monitored along the Garrison-Taft line. Monitoring included tracking sediment levels and aquatic insect and fish population in selected streams. In general, sediment levels rose during construction and fell to acceptable levels

Table 3. Examples of seeding mixtures used on a 500-kV line and on small wood structure lines.

Garrison-Taft 500-kV transmission line

Species[1]	Lbs/Acre
Smooth brome (*Bromus inermis*)	7.5
Thickspike wheatgrass (*Agropyron dasystachyum*)	5.0
Beardless wheatgrass (*Agropyron inerme*)	6.0
Sheep fescue (*Festuca ovina*)	1.0
Bluebunch wheatgrass (*Agropyron spicatum*)	7.5
Ladak alfalfa (*Medicago sativa*)	2.0
	29.0

Species[2]	Lbs/Acre
Tall fescue (*Festuca arundinaceae*)	5.5
Creeping foxtail (*Alopecurus arundinaceus*)	1.0
Red fescue (*Festuca rubra*)	1.5
Redtop (*Agrostis alba*)	0.3
Orchardgrass (*Dactylis glomerata*)	2.6
White Dutch clover (*Trifolium repens*)	0.7
	11.6

69- and 100-kV wood structure transmission lines
(at least 3 species from the list below were required in mixture)

Species	Lbs/Acre
Crested wheatgrass (*Agropyron cristatum*)	12.4
Thickspike wheatgrass (*Agropyron dasystachyum*)	13.4
Beardless wheatgrass (*Agropyron inerme*)	10.9
Streambank whetgrass (*Agropyron riparium*)	11.2
Western wheatgrass (*Agropyron smithii*)	18.8
Russian wildrye (*Elymus junceus*)	15.6
Sheep fescue (*Festuca ovina*)	12.4
Green needlegrass (*Stipa viridula*)	52.2
Orchardgrass (*Dactylis glomerata*)	4.2
Timothy (*Phleum pratense*)	3.4

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[1] Seeded on dry, relatively warm sites.

[2] Seeded on wet and cold sites, mid-to-high elevation slopes.

shortly after construction. Population changes of aquatic animals were not detected. Construction monitoring revealed sediment entering streams from some bridges and culverts. Seeding and rip-rapping corrected these problems. Where culverts blocked fish movements, baffles were installed to slow water velocity and plunge pools occasionally were built to raise the water surface to the culvert's level.

DNRC now addresses the spread of weeds by requiring line proponents to revegetate disturbed lands and develop weed control plans. These weed control plans, also required by the County Noxious Weed Control Act, also are reviewed by the district weed board. The plans typically specify repeated applications of herbicides. DNRC and the weed board evaluate the success of weed control on a site-specific basis. Cleaning construction vehicles of weed seeds and parts upon leaving infested areas is a standard mitigation contained in the Environmental Specifications. On the Missoula-Bonner line, weed spread was reduced by delaying construction in infested areas until the rest of the line was complete.

Wildlife Mitigations

Locally important wildlife habitats, such as riparian zones or grouse leks, can be preserved by placing supporting structures so the transmission line spans these habitats. Extra tall structures were used to allow the Garrison-Taft line to span conifers that shade an elk wallow. When routing or spanning wildlife use areas is not possible, the mitigations discussed below are used to reduce impacts.

The construction of transmission lines can be scheduled to decrease impacts in seasonally important wildlife areas. Where the Garrison-Taft line bisected elk winter ranges, construction was not allowed between December 1 and May 15. Construction on the identified calving ground was prohibited between March 15 and July 15. DNRC accommodated the construction needs of this large project by occasionally waiving the timing restriction. It granted waivers only at the written request of the builder and after joint review with the Montana Department of Fish, Wildlife and Parks(DFWP). DNRC will propose similar timing restrictions for deer winter ranges traversed by the Noranda mine line. Grouse breeding along the Fort Peck-Havre line was protected by prohibiting construction activities within 1/4 mile of those leks occupied by displaying grouse.

Many access roads along the Garrison-Taft line were closed to prevent entry into elk security areas; however, monitoring showed common violations of these closures. Small all-terrain vehicles could circumvent some gates and other gates were vandalized. More importantly, even the roads with effective gates improved access for walking hunters. Before the roads, the densely timbered, rugged terrain discouraged hunting in the elk security areas.

The line's sponsor, U.S DOE, funded a 5-year elk study to mitigate the impacts of the access roads. The study benefitted elk populations by (1) identifying remaining security areas in areas adjacent to the line; (2) protecting these areas through DFWP involvement in the U.S. Forest Service planning process; (3) providing data based on local elk ecology to facilitate elk management in the area; and (4) providing information that may serve to reduce the impact of future transmission line projects.

SUMMARY

The amount of land disturbed by transmission line construction is primarily determined by the line's length and the terrain it crosses (Table 1). Lines in mountainous terrain require graded roads to structure sites. On a per-mile-of-line basis, these roads disturb at least twice as much land as the nongraded trails associated with prairie transmission lines. Even when large structures are used, road and trail disturbance usually exceeds structure disturbance.

Physical impacts of transmission line construction center on the amount and intensity of soil disturbance. Disturbed soils tend to erode and encourage weed growth. Erosion can damage nearby aquatic habitats through sedimentation. Line construction can affect wildlife populations by displacing animals from critical ranges.

Soil and biological impacts are sometimes avoided by routing transmission lines around problem areas; however, the desire to reduce social impacts often prohibits this approach. Since soil-related problems are common to all lines, standard mitigations that limit disturbance, guide reclamation, and discourage weed spread are now required. Reseeding and installing drainage structures are generally successful in controlling erosion and sedimentation. Wildlife mitigations are developed as needed and may include restricting construction periods and gating access roads. The state-appointed monitor is essential to ensure that line builders understand and follow the required mitigations.

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Planning, Rehabilitation and Treatment of Disturbed Lands
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RECLAMATION AND REVEGETATION ALONG A 250-MILE 500 kV POWER LINE CORRIDOR

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ABSTRACT

Reclamation and revegetation success along the Montana Power Company Colstrip to Deepdale 500 kV powerline was monitored from 1985 through 1989. Followup revegetation was hampered by inadequate road and tower site earth work as a result of premature release of the reclamation bond. Drought conditions in 1985 and 1988 seriously affected revegetation efforts, especially on difficult sites. Weed control improved markedly, and all ROW areas are weed free except those next to infested range and cropland where a major cooperative effort is needed to control weeds. Access roads in previously unroaded areas resulted in changes of access, management practices, and cattle grazing behavior, all of which adversely affected revegetation success. Erosion, exacerbated by undersized culverts, the presence of very erodible soils, the occasional untrained contractor, is now the major ROW maintenance concern.

Observation of the revegetation efforts clearly shows the need for adequate and appropriate reclamation by qualified equipment operators up front, and a patient, measured effort of continued revegetation, weed control and erosion control over the long term. The bond period of 5 years may not be long enough to achieve the 90 percent revegetation success required by the permit. Future projects guidelines should consider look to a flexible timeframe and more realistic vegetation requirements to account for the affects of non-construction related impacts.

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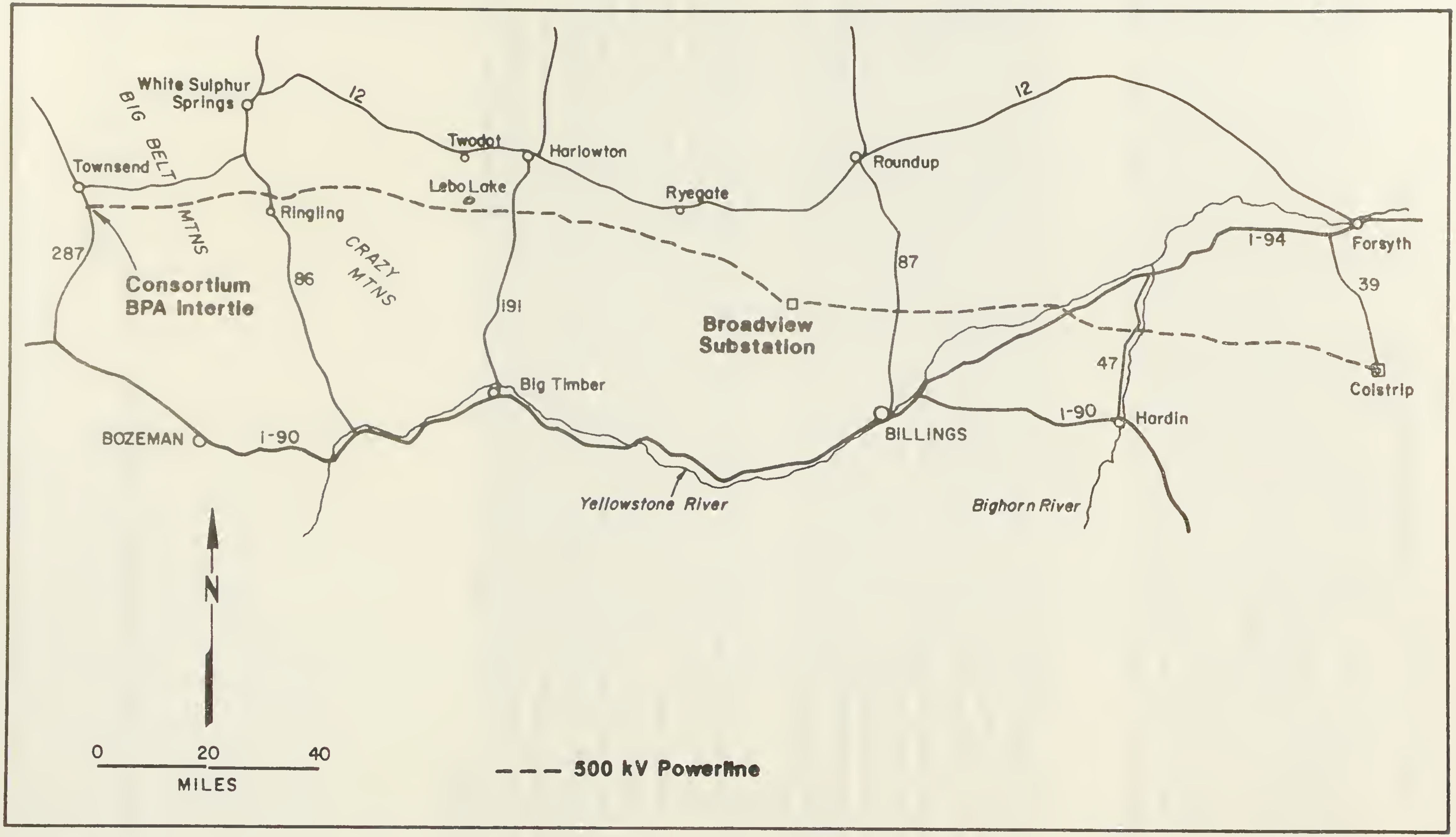
INTRODUCTION

Construction of the Colstrip-Broadview double-circuit 230 kV line began in 1975 after the centerline was approved by the Board of Natural Resources and Conservation. This double-circuit line was built to serve Colstrip Units 1 and 2. Colstrip Units 3 and 4 were granted a certificate in July 1977 and centerline approval for various line segments were granted later. The single-circuit 500 kV line segment built from Colstrip to Broadview for units 3 and 4 used existing right-of-way roads built for the Units 1 and 2 lines. From Broadview to Deepdale, south of Townsend, two parallel 500 kV lines with associated access and right-of-way roads were constructed in the early 1980s. (See Figure 1).

To ensure compliance with the Montana Major Facility Siting Act (Title 75, Chapter 20 - MCA), a set of construction guidelines was prepared by the Department of Natural Resources and Conservation (DNRC) and approved by the Board of Natural Resources and Conservation. Several specific sections of these guidelines were to play an important role in the dynamics of reclamation and revegetation, both during and following line construction. Two performance bonds were imposed; one in the amount of $1,000 per circuit-mile to ensure right-of-way and site restoration was placed on the contractor (constructor); and another of $200 per circuit-mile to ensure that reclamation and road closures have been effective was imposed on the Owner (Colstrip Project Consortium).

Detailed on-site monitoring was conducted by DNRC annually from 1985 through 1989 to assess revegetation success and weed control. Early inspections verified the success of weed control and revegetation. Later monitoring dealt with unforeseen impacts of cattle, access, land management, and intense precipitation. Toward the end of the 5-year bond period, it became apparent that a strict interpretation of the guidelines would preclude many segments of the powerline from achieving compliance with reclamation requirements which would enable them to be released from the bond. As a result, the Department of Natural Resources and Conservation recommended and the Board approved release of segments where impacts were caused by non-construction related activities.



Colstrip Units 3 & 4
Colstrip - Deepdale 500 kV Powerline
FIGURE 1

CONSTRUCTION GUIDELINES

When the Colstrip powerlines were built, the key to compliance with Montana's Major Facility Siting Act during and after construction is the Construction Guidelines approved by the Board in 1977. These guidelines often reflected the environmental sentiment of the times, as in Section 15. Other parts of the guidelines tried to address the potential affects of access, runoff, construction activities, and road location; but as is often the case where there is little data, they failed to hit the mark. Fortunately the Department and the Board recognized the problems and amended the guidelines as needed to ensure revegetation success. Several of the more important original guidelines are listed in part below.

1.0 General Guidelines for Contractor Performance

1.1 To assure compliance to the guidelines, the contractor submitted to the State of Montana a separate Performance Bond in the amount of $1,000 per circuit-mile of construction to ensure restoration of the right-of-way and adjacent lands which might have been damaged during the course of the construction. The entire bond was to be held in escrow until post-construction monitoring by the department indicated that all guidelines had been followed and revegetation was progressing satisfactorily, at which time the contractor was to be released from the performance bond. Following the contractor's release, the owner submitted to the State of Montana a Performance Bond in the amount of $200 per circuit mile of construction, to be held in escrow for five years, to ensure that reclamation and road closures had been effective where required.

5.0 Access Roads and Vehicle Movement

5.6 "Roads shall be located at the center of the right-of-way (that is, between the two 500 kV lines) insofar as possible, enabling traffic to avoid cables and conductors during the wire-stringing operation." Strict adherence to this guideline often resulted in extreme road impacts, when a location outside the ROW would have clearly minimized them.

6.0 Right of Way Clearing and Site Preparation

6.8 "All earth-moving equipment shall be operated only by qualified, experienced personnel." Road construction and reclamation clearly suffered under the attempts of unqualified operators.

11.0 Erosion and Sediment Control

11.9 "Culverts shall be of sufficient size to handle approximately 25-year floods. Culvert size shall be determined following procedures given in the Hydraulics Manual of the Montana Department of Highways (Peil and Weaver, 1975), or be equivalent standard procedures which take into account the variations in vegetation and climatic zones in Montana, the amount of fill, and the drainage area above the crossing". Lack of climatic data and the speed of runoff from high clay soils attested to the inadequacy of a 25 year-event as the design parameter.

15.0 Herbicides

"Herbicides shall not be used during construction or maintenance of this line." The problem is obvious. This guideline was amended immediately to allow mechanized spray units, licensed applicators and approved herbicides to be used for weed control.

16.0 Post-Construction Cleanup and Reclamation

16.2 "Grading and scarifying of roadways shall be required where appropriate and required by the landowner or the DEPARTMENT to restore the area to near natural conditions that will permit the growth of vegetation and discourage future traffic."

16.7 "Cross drains and water bars shall be added at an angle and as frequently as appropriate to satisfy road grades." Use of slope/soil type standards for waterbar frequency failed due to road use and precipitation intensity.

16.18 Revegetation shall not be considered complete until the following criteria are met:

> a. "In rangeland, coverage of perennial species shall be 30% or more of that on adjacent rangeland the year following revegetation, and 90% or more of the coverage of adjacent rangeland when the bond period is up."
>
> b. "In forest land, revegetated land exclusive of the right-of-way or permanent roads shall be stocked with trees by the end of the bond period so that the approximate stocking level of adjacent forest, or canopy closure, whichever is less, will be attained at maturity.
>
> The completion of revegetation shall be certified, after field inspection, by the DEPARTMENT or its agent."

POWERLINE CONSTRUCTION

The project was divided into segments from 35 to 60 miles to accommodate different major powerline contractors. All line construction was ground-based and each tower required a level crane pad. Most towers were a single-leg design utilizing a 4-way guy system and concrete mass deadmen. Self-supporting 4-leg towers were used at all corners to withstand torsional forces and in cultivated ground to eliminate guy wire interference with farm equipment.

Site disturbance resulted from crane pad construction, excavation for tower bases and deadmen, and rip trenches for buried sacrificial anodes and a counterpoise system. The number of structures averaged 4 to the circuit mile or about 1600 structures under the permit for Units 3-4.

Despite this large number of towers, most disturbance and subsequent reclamation/revegetation effort centered on access and right-of-way roads. In some cases, roads were built by the constructors own employees who were not qualified for such work, while other segments used a well-qualified subcontractor. Road segments prepared by qualified operators incurred less erosion damage during construction. Followup reclamation by the same contractor resulted in minimal land disturbance and an excellent seed bed for reseeding. Several tens of miles of access road prepared and reclaimed by unqualified operators still show the impacts of poor construction and reclamation.

Most of the line was fall planted by drill using a variation of the seed mix listed in Table 1. Steep slopes and areas requiring reseeding were broadcast seeded and either raked or harrowed. Areas which showed poor seed germination the following spring were immediately reseeded to ensure 1 year's growth before monitoring began.

TABLE 1

Common Name	Generic Name	*Pounds PLS per acre
pubescent wheatgrass	Agropyron trichophorum	4.5
tall wheatgrass	Agrophyron elongatum	3.0
western wheatgrass	Agropyron smithii	3.0
thickspike wheatgrass	Agropyron dasystachyum	1.5
Russian wild rye	Elymus junceus	3.0
* mix recommended for Dry Pasture		

A decision to release the contractor from the construction bond prematurely appears to have adversely impacted the revegetation effort. Guideline 1.1 states that post-construction monitoring by the Department indicating that "revegetation is proceeding satisfactorily" is a primary factor in releasing the Contractor from the construction bond. However, Montana Power Company (MPC), right-of-way manager for the consortium, recommended release of this first bond before seeding contractors began their work and the Department and Board approved. MPC reasoned that the changeover between construction contractors and revegetation contractors was an appropriate time to change from the construction bond to the revegetation bond; DNRC agreed. The revegetation contractors therefore had to complete earth preparation work at tower sites and along access roads. Several long-term problems resulted from this arrangement:

- The revegetation contractor often found that the site/road reclamation left for him was beyond the capabilities of his equipment.
- Downslope berms and improperly constructed waterbars left by the construction contractor were features that the seeding contractor failed to recognize as potentially problematic, both from his own experience and lack of guidance by the engineering contractor.

FIELD MONITORING

Post-construction monitoring was conducted from 1985 through 1989, corresponding to the 5-year performance bond time frame. All field monitoring was conducted through the use of ATVs supplied by MPC. The ATVs enabled the monitoring teams to quickly traverse long distances on difficult terrain. Initially, every tower site was documented as to condition of revegetation, weeds and erosion problems. Significant impacts, problems, and successes were documented in field notes and photographed to document success or failure over the bond period.

Monitoring in 1985, a severe drought year, concentrated on revegetation success and weed control. Cattle behavior in the form of overgrazing specific sites, unauthorized and inappropriate use of roads when wet, erodible soils, and very rocky tower sites were identified as potential long term problems. Weed varieties encountered along the line included, bull, canada and musk thistles, spotted and diffuse knapweed and leafy spurge.

Far better precipitation prevailed during the fall of 1985 and spring of 1986. Unfortunately, weeds and reseeded species both responded well. Weed control efforts were stepped up and Tordon combined with 2-4-D became the primary tool in controlling difficult weed species such as spotted knapweed and hounds tongue. Severe impacts from uncontrolled access and grazing pressure were recognized as non-construction related problems that could preclude bond release under the guidelines. In consideration of these impacts, DNRC recommended release of 120.29 circuit miles of line in March, 1987.

Very severe thunderstorms in May and June of 1987 affected nearly 60 miles of line from Colstrip to Broadview. Several culverts at locations not suited to rock crossings were replaced with more or larger pipes; otherwise the pipe was removed and a crossing built. Tower sites and several long road sections with severe erosion were reseeded and covered with erosion control mats, especially in areas of erodible soils. Cattle continued to affect tower sites through severe trampling, using guy turn buckles for scratching and creating trails on roadways. By this time weeds were only a problem where there was no off right-of-way weed management. Extensive waterbar and erosion control work was started following the 1987 monitoring. DNRC recommended bond release along segments where management problems precluded 90 percent vegetation recovery. A total of 47.77 circuit miles were released in early 1988.

Though 1988 was generally a severe drought year, right-of-way vegetation did quite well where it was established. Major problems resulted from poor waterbar construction over 60 miles of line; all of which were repaired in 1989. Cattle, road use, localized erosion, and off right-of-way weed problems were deemed maintenance problems not appropriately covered under the performance bond. DNRC recommended release of over 150 circuit-miles of line considering that all remaining impacts were non-construction related.

In the final year of bonding, 1989, it was apparent that revegetation was a complete as it could be given associated management, cattle behavior, access and weather constraints. Right-of-way weeds were only a limited problem due mostly to weed spread by vehicles and cattle from nearby seed sources. Erosion problems were being addressed by adding more waterbars, extensive use of erosion control matting and, where possible, use of straw bales in road ruts and drainways. Construction related impacts were considered mitigated and the remaining 53 circuit-miles of line was released.

CONCLUSION

Despite initial problems with several of the Colstrip Units 3-4 Construction Guidelines, the Department and Board worked closely with Montana Power Company to address impacts as efficiently as possible through guideline amendments.

Unpredictable cattle behavior (a non-construction source of impacts) will continue to cause severe localized impacts to sites and roadways. It is now clear that cattle prefer level, grassed, sagebrush-free roads over winding trails on hillsides; and that the shade provided by the large towers, however limited, is better than no shade at all.

ROW road management by the landowner took many forms but the greatest impacts from this source were from access and right-of-way road modifications. On several large ranches, roads are bladed on a yearly basis. Where this took place on the right-of-way, vegetation was removed, waterbars destroyed and roadside berms created-all contrary to the efforts of DNRC and the MPC to control erosion. Any segment which incurred landowner modification was released from bond after the landowner was notified of the compliance requirements and reasons for release. In 1988 nearly 15 miles of already released line north of the Crazy Mountains were affected by construction of a fireline road adjacent to the right-of-way road. In this instance the landowners were informed that any weed problems that resulted were their responsibility.

DNRC's 5-year monitoring effort made very clear the differences between reclamation on a controlled site, such as a strip mine with fairly uniform physical and vegetative characteristics and a long easily accessible project with a variety of soil, geologic, climatic and vegetative characteristics. In regulating impacts to linear facilities, and during subsequent mitigation, consideration of all impact sources is absolutely essential, and much broader in scope than normally encountered in strip-mine activity.

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

LONG-TERM EVALUATION OF PIPELINE RIGHTS-OF-WAY REVEGETATION IN THE BIG HORN BASIN, WYOMING

K. L. Johnson[1] and H. G. Fisser[2]

ABSTRACT

University of Wyoming researchers established 17 widely separated plots to evaluate revegetation along a 100-mile segment of a natural gas pipeline right-of-way from Elk Basin to Lost Cabin, Wyoming shortly after pipeline closure during fall 1972. The objectives of the study were to evaluate 1) plant species suitable for revegetation of rangelands disturbed by pipeline construction, 2) methods of seeding, and 3) environmental factors limiting seedling establishment. Plots were located to represent a diversity of soils and vegetation characteristics. Each plot was seeded with 16 grasses, 7 forbs, and 7 shrubs. The plots were evaluated for germination and establishment in 1976. Long-term survival was evaluated in 1982 and again in 1986, with a brief survey of surviving species alone in 1989.

There was no clear germination pattern attributable to either plot or seeding method. Poorest stand ratings occurred on an alkaline bottomland and on a saline upland. However, loamy upland sites and sites within communities of big sagebrush (Artemisia tridentata), blue grama (Bouteloua gracilis) and other grasses maintained a variety of planted species, although competition from native species sometimes was responsible for loss of seeded plants. Most successful grasses planted were: Russian wildrye (Elymus junceus), western wheatgrass (Agropyron smithii), fairway crested wheatgrass (A. cristatum), nordan crested wheatgrass, and critana thickspike wheatgrass (A. dasystachyum). Rambler alfalfa (Medicago sativa) remained on one site in 1986, but it and all other forbs were absent on the other 16 plots. Success was minimal with most woody species, although winterfat (Ceratoides lanata), rubber rabbitbrush (Chrysothamnus nauseosus) and big sagebrush and were able to survive. Study results over a 17-year period thus indicate that differences in site characteristics are very important in determining revegetation success in an arid environment, and that certain perennial grasses are more efficient as initial seeded colonizers of denuded rights-of-way than forbs or shrubs. Further, it is well to encourage reestablishment of resident plants, especially woody chenopods, by blading rights-of-way no more than is strictly necessary.

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INTRODUCTION

Energy development in the Intermountain Region commonly involves construction of buried pipelines to transfer petroleum products over long distances. Because construction of such facilities normally entails blading of the right-of-way for a distance of about 50 feet on either side of the pipeline itself, considerable surface area is denuded of resident vegetation and requires rehabilitation, usually by seeding with species adapted to local growing conditions.

During the period 1971-72, Colorado Interstate Gas Corporation (CIG) constructed a natural gas pipeline through the Big Horn Basin of Wyoming on a general northwest-southeast line from Elk Basin to Lost Cabin. Approximately 100 miles of disturbed rights-of-way resulted, distributed over several different soils, slopes, aspects and vegetation types. CIG funded a study at the University of Wyoming to learn more about the practical rehabilitation of such disturbed lands in semi-arid areas like the Big Horn Basin. The objectives were to evaluate 1) plant species suitable for reseeding in different vegetation types, 2) methods of seeding, and 3) environmental factors limiting seedling establishment. The study was designed to improve pipeline rehabilitation programs for better wildlife and livestock forage production, and for reduction of erosion with associated improvement of watershed characteristics.

METHODS

During the fall of 1972, 17 sites along the pipeline were selected and numbered 1 to 17 from northwest to southeast, from about milepost 8 to milepost 103. The sites represented major soil and vegetation types through which the pipeline passed as shown in Table 1. Basic soil characters were defined from one sample of surface soils at each site. Average annual precipitation varied from about 6 to 10 inches (140-250 mm), and mean annual temperature from about 40° to 46°F (4-8°C) among the plots. Elevations ranged from about 4400 to 5200 ft (1340-1585 m).

The sites were seeded during the first week of November, 1972 with sixteen species of grasses, seven forbs and seven shrubs thought to be adapted to semi-arid, northern growing conditions (Table 2). All plots were seeded with all species except plot 1, which received no winterfat, and plot 16, lacking small burnet and antelope bitterbrush.

Plots 1 through 12 were seeded with a shoe-type, 4-row, tractor-mounted seeder. Eight rows of each species were seeded at 14-inch spacings, except for winterfat and big sagebrush, seeded at fewer rows (usually 1-3) on nine of the plots due to a lack of seed. Plots 13 and 14 were seeded with a rangeland drill, set at 12-inch spacings. Ten rows of each species were seeded on plot 13, five on plot 14. The remaining plots (15 through 17) were seeded with a hand planter into furrows made with the rangeland drill. Six rows were seeded on plot 15 and ten rows on 16 and 17, except for the shrubs on plot 16 (6-7 rows). On all plots, winterfat, big sagebrush, rubber rabbitbrush and blue grama were broadcast into the furrows and then covered. Seedings were not conducted at a set seeding rate, except that ample seed was planted to rule out the complication of inadequate seed numbers.

Table 1. Characteristics of pipeline seeding plots.

Plot No.	Location			Soil Tex. Class[1]	Soil Org. Matter	Soil pH	Vegetation Dominants[2]
	Mile-post	Mile/ Dir.	Site		Percent		
1	8 -	0.3 N	Gravelly upland	SL	1.4	7.3	Artr/Agsp
2	8 -	0.4 S	Alkaline hardpan	CL	1.1	8.0	Arpe/Orhy
3	40 -	0.1 S	Saline bottomland	SL	0.6	7.9	Save
4	41 -	0.3 S	Gravelly upland	SL	1.4	7.2	Artr/Bogr
5	60 -	0.3 S	Sandy loam breaks	SL	0.8	7.9	Atga/Artr
6	62 -	0.3 S	Sandy loam upland	SL	1.0	8.1	Atga/Orhy
7	63 -	0.15 S	Badland	Sil	0.4	7.8	Mostly bare
8	64 -	0.1 N	Sandy loam upland	SL	0.8	8.1	Atga/Artr
9	65 -	--- S	Saline upland	L	0.6	7.9	Atga/Bogr
10	68 -	0.4 N	Sandy upland	SL	0.7	7.3	Artr/Bogr
11	77 -	0.2 N	Sandy upland	LS	0.7	6.5	Bogr/Oppo
12	81 -	0.25 S	Sandy upland	LS	0.2	6.1	Artr/Bogr
13	89 -	0.1 S	Sandy upland	LS	0.9	7.7	Artr/Bogr
14	92 -	0.2 N	Sandy breaks	LS	1.1	6.2	Artr/Agsp
15	100 -	0.2 S	Loamy upland	L	1.3	7.7	Artr/Agsp
16	102 -	--- S	Saline bottomland	Sil	1.7	7.7	Save/Agsm
17	103 -	0.2 N	Loamy upland	CL	1.0	7.9	Artr/Agsp

[1] SL = Sandy loam; CL = clay loam; L = loam; LS = loamy sand; Sil = silts

[2] Artr = *Artemisia tridentata*; Arpe = *A. pedatifida*; Atga = *Atriplex gardneri*; Save = *Sarcobatus vermiculatus*; Oppo = *Opuntia polyacantha*; Agsp = *Agropyron spicatum*; Orhy = *Oryzopsis hymenoides*; Bogr = *Bouteloua gracilis*; Agsm = *Agropyron smithii*

All plots were pitted with a 3-point mounted, 4-eccentric disc pitter to evaluate the effects of surface pitting to improve soil moisture conditions. Plots 9 and 13 through 17 were fully pitted. Only half of the remaining plots were treated to allow comparison with the non-pitted side. All plots were seeded at right angles to the pipeline and pitted parallel to it except plot 15 that was both seeded and pitted on the contour. The plots were not fenced and had no protection from grazing animals at any time in the evaluation period.

The seeded plots were evaluated for species presence twice in 1973 (May-June and September), and in July of 1974, 1975 and 1976. Germination and seedling presence were regarded as complete by July 1974; permanent establishment was considered as complete by 1976. Long-term survival was evaluated in 1982 and again in 1986. A brief survey of surviving species alone was made in 1989. Germination, establishment and survival of the seeded species were rated by ocular estimate on the following scale: 0 = none; Poor (P) = occasional plants; Fair (F) = < 1 plant/foot of row; Good (G) = 1-2 plants/foot of row; Excellent (E) = > 2 plants/foot of row. Between-grade ratings were also employed as necessary.

Table 2. Species seeded on pipeline plots.

Growth Form Common Name	Scientific Name
Grasses	
Alkar tall wheatgrass	*Agropyron elongatum* (Host.) Beauv.
Alta tall fescue	*Festuca arundinacea* Schreb.
Basin wildrye	*Elymus cinereus* Scribn. & Merr.
Beardless wildrye	*Elymus triticoides* Buckl.
Blue grama	*Bouteloua gracilis* (H.B.K.) Lag.
Critana thickspike wheatgrass	*Agropyron dasystachyum* (Hook.) Scribn.
Fairway crested wheatgrass	*Agropyron cristatum* L. Gaertn.
Green needlegrass	*Stipa viridula* Trin.
Greenar intermediate wheatgrass	*Agropyron intermedium* (Host.) Beauv.
Luna pubescent wheatgrass	*Agropyron tricophorum* (Link) Richt.
Mandan ricegrass	*Oryzopsis hymenoides* (Roem. & Schult.) Ricker
Nordan crested wheatgrass	*Agropyron desertorum* (Fisch.) Schult.
Rosana western wheatgrass	*Agropyron smithii* Rydb.
Russian wildrye	*Elymus junceus* Fisch.
Sherman big bluegrass	*Poa ampla* Merr.
Whitmer beardless wheatgrass	*Agropyron inerme* (Scribn. & Smith) Rydb.
Forbs	
Cicer milkvetch	*Astragalus cicer* L.
Eski sainfoin	*Onobrychis viciaefolia* Scop.
Palmer penstemon	*Penstemon palmeri* Gray
Rambler alfalfa	*Medicago sativa* L.
Sicklepod milkvetch	*Astragalus curvicarpus* (Sheld.) MacBride
Small burnet	*Sanguisorba minor* Scop.
White-flowered prairie clover	*Petalostemum candidum* Michy.
Shrubs	
Antelope bitterbrush	*Purshia tridentata* (Pursh) DC
Big sagebrush	*Artemisia tridentata* Nutt.
Fourwing saltbush	*Atriplex canescens* (Pursh) Nutt.
Nuttall saltbush	*Atriplex gardneri* (Moq.) Dietr.
Rubber rabbitbrush	*Chrysothamnus nauseosus* (Pall.) Britt.
Shadscale	*Atriplex confertifolia* (Torr. & Frem.) Wats.
Winterfat	*Ceratoides lanata* (Pursh) J.T. Howell

RESULTS

Germination and Establishment

Generally, there was observable germination of a majority of the seeded species on all plots during the first growing season after seeding. The first evaluation in late May to early June, 1973 showed that all species seeded had germinated on plots 5, 6, 7, 8, 9, 10, 15, 16 and 17 (Table 3). Germination was least evident on plots 3, 4 and 12, where only 13, 15 and 17 of the 30 species planted, respectively, had emerged by the first week of June. Although germination/emergence scorings were frequently in the poor category (occasional plants), there was no clear pattern attributable either to plot or seeding method. In addition, the general presence of seedlings indicates that all seeding methods were effective and that overwinter moisture supplies were adequate. There was no evident effect of pitting on germination/emergence scorings.

Growing conditions during the year following emergence induced significant mortality among the seedlings, so the final estimate of germination was placed at the end of the second growing season (July 1974) on plots 5 through 17 and the end of the third season (July 1975) on plots 1 through 4. Species emergence rated as fair-good or better ($\geq$ 1 plant/foot of row) are listed by plot in Table 4.

Table 3. Germination ratings of 30 seeded plant species in the first growing season by plot and seeding method.

Plot[1]	Seeding Method	Germination Ratings E	G-E	G	F-G	F	P-F	P	O-P	O
		Number species								
1	Shoe-type Seeder	1	1	9		4		6	1	7
2	"	4		4		6		7		9
3	"					3	2	6	2	17
4	"		3	2	2	5		2	1	15
5	"			3	1	9	6	11		
6	"						9	21		
7	"			1	1	2	7	19		
8	"			2		4	9	15		
9	"				1	2	7	20		
10	"			1		4	9	16		
11	"	10		3		3		11	1	2
12	"	3		4		6		4		13
13	Rangeland Drill	16	2	1		5		3	1	2
14	"	12		7		4		3	1	3
15	Hand Planter	5		2		10	4	9		
16	"	1	1	5		7	3	11		
17	"	4		3	1	9	2	11		

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[1] 29 species seeded on plot 1; 28 on plot 16.

Table 4. Species showing significant (F-G to E) germination/emergence by 1974 and establishment by 1976 on pipeline plots seeded in 1972.

Growth Form Species	Plots[1]
Grasses	
Alkar tall wheatgrass	1, 2, ~~5,~~ ~~9,~~ 13, 14, 15, 16, 17
Alta tall fescue	~~15~~, ~~17~~
Basin wildrye	1, 10, 13, 14, 15, 17 11
Beardless wildrye	14, 15 13
Blue grama	1, ~~9,~~ 15
Critana thickspike wheatgrass	1, 2, 4, ~~6,~~ 7, 8, ~~9,~~ 11, 13, 14, 15, 16, 17 10
Fairway crested wheatgrass	1, 2, 4, 5, 8, 13, 14, 15, 16, 17 11
Green needlegrass	1, 5, 8, 15, 17 4, 10, 13, 16
Greenar intermediate wheatgrass	15, ~~17~~ 14
Luna pubescent wheatgrass	1, 2, ~~5,~~ 14, 15, 17 13
Mandan ricegrass	1, ~~2,~~ 4, 5, 7, 15
Nordan crested wheatgrass	1, 2, 4, 5, 8, 9, 11, 13, 14, 15, ~~16,~~ 17 10
Rosana western wheatgrass	1, 2, 4, 5, ~~8,~~ ~~9,~~ 13, 15, 17 10, 11, 14, 16
Russian wildrye	1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16, 17
Sherman big bluegrass	1
Whitmar beardless wheatgrass	1, 14, 15 13, 17
Forbs	
Cicer milkvetch	~~1,~~ ~~15,~~ ~~16~~, ~~17~~
Palmer penstemon	15, ~~17~~ 14
Rambler alfalfa	1, 2, 15
Shrubs	
Big sagebrush	13, 14
Fourwing saltbush	13
Nuttall saltbush	1, 5, 6, 8, 9, 13, 15
Rubber rabbitbrush	1, 2, 10, 12, 13, 14, 15, ~~16~~
Winterfat	2, 11, ~~12,~~ 13, 14, 15, ~~16,~~ ~~17~~

[1] - Underlined plot numbers indicate those species gaining significant (F-G to E) rating from 1974 to 1976; plot numbers struck through indicate species losing significant rating during the same period.

Opposite trends affected several of the plots during the establishment period from the summer of 1974 through the growing season of 1976. First, some plantings rated at less than fair-good in 1974 improved to that level or higher in the succeeding two years (Table 4). The process was especially prominent on plots 10-14, with the exception of plot 12 where improvement came even later. These plots were located on sandy uplands, and showed baseline establishment of 3-4 new species per plot. The late development may have been due to delayed germination of seeds planted too deeply in the sandy soils, or to expansion of sod-forming species. Green needlegrass and western wheatgrass were especially prominent in the process.

Second, growing conditions in the two-year establishment period induced significant reduction in the presence ratings of many species on several plots, particularly the saline and heavy-soil sites (Table 4). Plot 9 (a loamy upland), plot 16 (a saline bottomland), and plot 17 (a gravelly upland), each had the presence ratings of 4-5 species degrade to less than the fair-good level. As a result, cicer milkvetch and Alta tall fescue each joined the list of species failing to become established to a baseline level on any plot.

At the end of the establishment period, fifteen grasses, two forbs and five shrubs continued to have fair-good or better presence ratings on at least one site. Ten grasses, no forbs and three shrubs had attained that level on four or more sites. There was no significant effect of pitting on establishment of species, either within the same plot or between plots. Establishment on the refilled pipeline furrow itself, however, was significantly lower than on the rights-of-way.

Long-term Survival

During the thirteen-year period 1977-1989, seasonal and year-to-year variation in growing conditions served to test the long-term survivability of species deemed to have been well established in 1976. The period contained extremes in climate (precipitation and temperature), together with complete exposure to insect and pathogen outbreaks as well as grazing by both livestock and wildlife. Therefore, species exhibiting significant (F-G to E) presence after 17 growing seasons can be regarded as those offering the best possibilities for rehabilitation of pipeline rights-of-way under the semi-arid conditions of the Bighorn Basin.

Generally, most species incurred major reductions in the number of plots showing significant presence ratings between 1976 and 1986. The loss was offset on several sites by the general reestablishment of native species. Less than two-thirds (63%) of the seeded stands rated as significant in 1976 maintained that level over the succeeding decade (Table 5). The forb species, never strongly established, were reduced to a single stand of alfalfa on plot 15. About half of the strongly rated shrub stands declined, and a quarter of the grasses. Four grass species (beardless wildrye, intermediate wheatgrass, ricegrass and big bluegrass) joined tall fescue in failing to maintain a significant presence on any plot. Conversely, Russian wildrye and Fairway crested, Nordan crested and western wheatgrasses maintained or increased their significant ratings overall, while thickspike and pubescent wheatgrasses each brought one new stand to at least a F-G level, partially offsetting their losses. Between 1986 and 1989, 7 grass stands failed to maintain a significant ranking, concentrated on plots 16 and 17. Tall wheatgrass joined the list of species not having a significant ranking on any plot. Thus, the overall long-term survival of stands rated as significant in 1976 remained at 63% by 1989, consisting of 73 grass, 1 forb and 12 shrub stands. Eight grasses, no forbs and two shrubs attained that level on three or more sites. Except for sandy sites, the refilled pipeline furrow remained in a generally lower stage of reclamation.

DISCUSSION

Rehabilitation of semiarid areas similar to those studied can be achieved either through direct reclamation or through survival/secondary succession of native plant materials. Although many of the seeded grasses did well, whenever possible it is well to encourage reestablishment of resident plants, especially shrubs, by blading rights-of-way no more than is strictly necessary. In addition, surviving plants provide seed sources for propagation into open areas. Aside from the smaller size of the shrubs, the native plant community of several sites, especially those dominated by woody chenopods, is now virtually the same as the adjacent non-bladed area.

If reclamation is employed, the choice of species to seed should be confined to the adapted native and introduced grasses. Seeding of forbs should not be attempted, and shrubs should be seeded only under carefully selected conditions of soils and grazing protection. In general, light, well-drained soils can be seeded most successfully. Heavy, poorly drained soils and saline soils are best treated by encouraging reestablishment of resident plants. Seeding of such sites when carefully done can provide additional and transitory cover before

Table 5. Species showing significant (F-G to E) long-term survival by 1986 on pipeline plots seeded in 1972.

Growth Form Species	Plots[1]
Grasses	
Alkar tall wheatgrass	~~15~~, ~~16~~, ~~17~~
Basin wildrye	11, 14, 15, 17
Blue grama	15
Critana thickspike wheatgrass	2, 4, 8, 10, 11, 15, ~~16~~, 17 12
Fairway crested wheatgrass	1, 2, 4, 5, 8, 11, 13, 14, 15, 16, 17 10, 12
Green needlegrass	1, 10, 15, ~~17~~
Luna pubescent wheatgrass	14, 15, 17 12
Nordan crested wheatgrass	1, 4, 5, 8, 10, 11, 13, 14, 15, ~~16~~, 17 12
Rosana western wheatgrass	1, 2, 4, 5, 10, 11, 13, 14, 15, 16, 17 7, 12
Russian wildrye	1, 2, 4, 5, 6, 8, 9, 10, 11, 13, 14, 15, 16, 17 12
Whitmar beardless wheatgrass	15, ~~17~~
Forbs	
Rambler alfalfa	15
Shrubs	
Big sagebrush	13, 14
Nuttall saltbush	5, 6, 8, 9, 15
Rubber rabbitbrush	12, 14
Winterfat	13, 14, 15

[1] - Underlined plot numbers indicate those species gaining significant (F-G to E) rating between 1976 to 1986; plot numbers struck through indicate species losing significant rating from 1986 to 1989.

the native plants become reestablished. Badland sites (bare or nearly bare soils) should not be seeded or otherwise treated. The adverse growing conditions indicated by the lack of native vegetation effectively preclude reclamation through seeding programs. Reclamation of the pipeline trace itself is generally unlikely. No resident plants remain, and the transfer of subsoil materials to the surface, generally salty and deficient in plant nutrients, normally inhibits establishment of new plant growth. Salvage and reapplication of topsoil would be required for pipeline trace reclamation.

Although germination was generally evident across all the plots during the first growing season, on-site conditions soon induced strong differences in the presence scoring of species. Only five grass species proved themselves capable of general success: Russian wildrye, Nordan crested wheatgrass, Fairway crested wheatgrass, Rosana western wheatgrass, and Critana thickspike wheatgrass. On light, well-drained soils, a further three grasses have promise: basin wildrye, green needlegrass, and pubescent wheatgrass. Of all these the grass of choice would be Russian wildrye, with long-term success on 15 of the 17 plots and presence on the remaining two.

Aside from Rambler alfalfa on one plot none of the seeded forbs attained significant success on any plot and not even presence on most plots. It appears that the forb species used in this study were not adapted to the growing conditions of the area and should not be seeded.

On light well-drained soils, three shrub species (big sagebrush, rubber rabbitbrush and winterfat) attained long-term success on two or three plots, indicating that selective reclamation can be achieved. Chances of success are improved if locally-adapted plant materials are used, and if some measure of grazing protection can be provided because the young shrubs appear to be subjected to heavy grazing use.

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

PIPELINE CONSTRUCTION IN NOVA'S ALBERTA GAS TRANSMISSION DIVISION

S. Landsburg and A.W. Fedkenheuer[1]

ABSTRACT

NOVA Corporation of Alberta is a major Canadian energy company involved in natural gas transportation and marketing, petroleum, petrochemical manufacturing, consulting and research. The Alberta Gas Transmission Division (AGTD) of NOVA Corporation has installed more than 14,000 km of primarily natural gas pipeline since its inception in 1954. It continues to operate and maintain and expand this system. This paper discusses Alberta government pipeline regulatory requirements as they apply to NOVA's AGTD activities. It also outlines the summer construction topsoil handling techniques of no topsoil stripping, ditchline stripping, blade width stripping, ditchline and spoil side stripping and ditchline, spoil side and work side stripping. The paper concludes with a discussion of the winter construction soil handling techniques of ditchline stripping and no topsoil stripping.

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INTRODUCTION

NOVA Corporation of Alberta (NOVA) is a major Canadian energy company involved in natural gas transportation and marketing, petroleum, petrochemical manufacturing, consulting and research. The Alberta Gas Transmission Division (AGTD) of NOVA is concerned with natural gas system design, pipeline construction, research and facility operations throughout the province of Alberta. Since its inception in 1954, the AGTD has installed more than 14,000 km of natural gas pipeline and continues to operate, maintain and expand this system.

This paper outlines Alberta government regulatory requirements for pipelines and discusses typical pipeline construction techniques used within the AGTD.

ALBERTA LEGISLATION

General Reclamation Legislation

Prior to 1963 there was no legislated requirement for the reclamation of disturbed lands in Alberta. Through the 1940's, 1950's and into the 1960's the province of Alberta experienced a rapid increase in resource development, especially in the petroleum industry. The combination of increased resource development activity and public concern resulted in the Surface Reclamation Act being proclaimed in 1963 (Brocke 1988).

The Surface Reclamation Act was the first provincial legislation that dealt specifically with reclamation of disturbed land. It applied only to surveyed land and was directed mainly at the petroleum industry (Brocke 1988). At this same time, the Surface Reclamation Council was created to enforce the requirements and issue reclamation certificates upon completion of reclamation. The standards of the day were remedial. Operators were required to leave the land in a condition that would not interfere with adjacent agricultural operations. Generally this entailed levelling, contouring, removing rocks and other debris, cultivation, weed control and the replacement of fences. Soil conservation was not required (Brocke 1988).

Through the 1960's and into the 1970's environmental activists voiced displeasure with environmental protection measures. In 1973, ten years after the passage of the Surface Reclamation Act, a new act, the Land Surface Conservation and Reclamation Act, was proclaimed. This Act marked a distinct change in attitude and approach to reclamation. Whereas the Surface Reclamation Act required resource developers to clean up after the damage was done, the new Act required environmental protection and reclamation be a part of the development planning and integrated with the operation. A review and approval system including Environmental Impact Assessments and Development and Reclamation Approvals was instituted. The concept of a security deposit was established to provide an incentive to developers to conduct reclamation.

Operators must obtain a Reclamation Certificate to have their deposit returned (Brocke 1988).

Since 1973, the Surface Reclamation Council has been expanded and become known as the Land Conservation and Reclamation Council (the Council). The objectives of the Council are to protect the environment by ensuring that development and reclamation plans anticipate problems, minimize the effect of surface disturbance, and return disturbed land to an equivalent land capability at the time of abandonment (Brocke 1988). The return of equivalent capability does not imply that the various types of land capability will be identical to pre-disturbance conditions, rather it provides for flexibility such that individual capabilities may change, but overall capability will be equivalent to pre-disturbance.

The Council defines land capability as the ability (ability unaltered by any level of future management inputs, activities or alterations) of land resources to support a given land use on a sustained basis. Land capability refers to an evaluation of the chemical and physical characteristics of land and the determination of inherent or natural abilities of land resources to provide for use. It includes any existing abilities and conditions which are the result of alterations or management practices prior to the development (Brocke 1988).

The concept of "reclamation" of land is considered by the Council (Brocke 1988) to include all desirable and practicable methods for:

- designing and conducting a surface disturbance in a manner that enhances the reclamation potential of the disturbed land to an equivalent capability;
- handling material in a manner that ensures reconstructed soils have an equivalent land capability relative to the soils that existed prior to disturbance;
- contouring the surface to minimize hazardous conditions, ensure stability, protect the surface against wind or water erosion, and provide for surface drainage;
- revegetating and managing the land to meet the land capability objective; and
- re-establishing surface water resources.

Pipeline Specific Legislation

A regulated pipeline is defined in Section 1(h) of the Regulated Oil and Gas Pipeline Surface Regulations (A.R. 207/76 and 161/79) as a pipeline that is both 150 mm (6 in) or more in diameter and 16 km (10 mi) or more in length. This definition also includes pipeline gathering and distribution systems which have at least 16 km or more of pipeline in total with diameters of 150 mm or greater (Alberta Environment 1988).

Pursuant to Section 4(1) of the Regulations, before commencing the construction, operation, alteration, extension or abandonment of a regulated pipeline, the proponent shall make application for Development and Reclamation (D & R) Approval. In accordance with Section 2 of the Regulation, D & R Approval is also required for the alteration, extension or abandonment of a regulated pipeline in existence prior to the enactment of the Regulations on September 1, 1976.

The purpose of preparing a D & R Application is to address environmental concerns and mitigation of adverse environmental impacts during the construction, operation, maintenance and abandonment of a pipeline. It documents the project description, selection of alternate routes, selection of the preferred route, soil investigations for the preferred route and the environmental protection plan (Alberta Environment 1988).

Upon receipt of the D & R Application, Alberta Environment coordinates an environmental review of the application by government agencies. Once the environmental issues surrounding the proposed pipeline are satisfactorily addressed, Alberta Environment issues the proponent a D & R Application number. The normal D & R application review process takes approximately 45 days if the application is complete.

Once the D & R Approval is issued, the procedures specified in the Environmental Protection Plan (EPP) are legally enforceable. The proponent is responsible for ensuring that the contractor complies with the terms of the D & R Approval and EPP. Construction activities outlined in the EPP are monitored by the Reclamation Officers of Alberta Environment and Alberta Forestry, Lands and Wildlife.

PIPELINE CONSTRUCTION TECHNIQUES

Specific materials handling procedures are developed for each pipeline construction project. The type of procedure(s) used are based on a number of factors such as: right-of-way (RoW) width, land use, season, depth of topsoil, equipment availability, subsoil quality, and soil type. Soil conservation and the maintenance of equivalent land capability are major environmental issues concerning pipeline construction within Alberta (pers. comm., Dec. 29, 1989, Ralph Dwyer, Linear Projects Section Head, Land Reclamation Division, Alberta Environment). As a result, the AGTD makes every effort to use procedures which address these issues. The environmental objectives associated with each pipeline construction project are: to minimize the disturbance of topsoils not stripped; to minimize the loss of topsoil and subsoil materials; to sustain the quality of topsoil on the RoW; to prevent the compaction of soil horizons; to utilize procedures that allow for effective reclamation; to minimize impacts on wildlife and fisheries; and to minimize impacts on water quality (NOVA 1988).

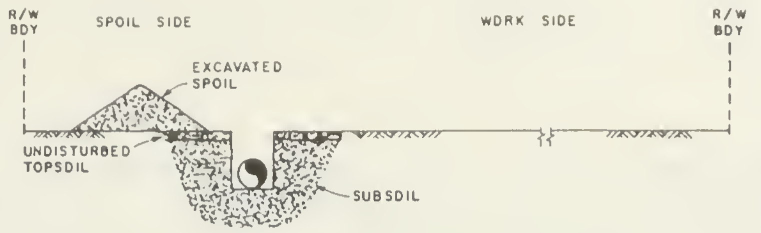
Summer Construction

No Topsoil Stripping. The AGTD considers it impractical to conserve topsoil where topsoil depth is less than 10 cm (4 in). If landowners request the option of no topsoil stripping, AGTD personnel discuss the possible consequences with them and contact the appropriate reviewing agencies before proceeding (NOVA 1988). Using this procedure, no topsoil is stripped or salvaged on the RoW prior to trench excavation (Fig. 1). Topsoil and subsoil are excavated together as a single lift and placed on the spoil side of the trench. A wheel ditcher is preferred for excavation since the spoil can be backfilled without creating an excessive roach. Where required (stony or poorly drained areas, road crossings, bends, pipeline crossings) a backhoe is used. Compaction of backfill material is done immediately following spoil replacement to reduce the height of the roach and to not impede surface drainage (Alberta Environment 1985).

Ditchline Stripping. This procedure removes topsoil to a width that corresponds to the expected ditch size of 0.8 to 1.2 m (2.5 to 4 ft). This procedure is used in pasture and hay land where there is a well developed sod layer and topsoil and subsoil materials can be placed on top of the vegetation. The assumption is that most of the spoil material can be removed from the vegetation on the spoil side without causing scalping of the sod. As well, backfill material will usually not overflow the trench, as a sufficient volume of topsoil will have been salvaged to replace the original depth of topsoil stripped over the trenchline (Alberta Environment 1985).

The adjustable step-blade is the preferred method for ditchline stripping. This piece of equipment, developed and owned by NOVA, is mounted on a D-8 bulldozer and can strip a path approximately 1.2 m (4 ft) wide. Topsoil stripping depths can be adjusted hydraulically from 0 to 35 cm (14 in). Using this procedure, topsoil is removed and placed beside the trench on the work side of the Row. Subsoil is removed using a wheel ditcher and placed beside the trench on the spoil storage side of the Row (Fig. 2). When replacing spoil, care is taken to ensure it is returned to the trench and not excessively roached over the trench or allowed to overflow the trench on to undisturbed topsoil.

Blade Width Stripping. This procedure removes topsoil from an area the full width of a bulldozer or grader blade of 3 to 4 m (10 to 13 ft) centred over the trenchline. This procedure produces the least mixing of topsoil and subsoil by accommodating the backfill and replacement of trench spoil without affecting adjacent undisturbed topsoil (Alberta Environment 1985). Blade width stripping is used on pasture land, hay land and some bush lands. Blade width removes more topsoil material than ditchline stripping and may be chosen over ditchline stripping based on the: distance to be stripped; equipment availability; subsoil characteristics; topsoil depth; topsoil pile size; and land use (NOVA 1988).



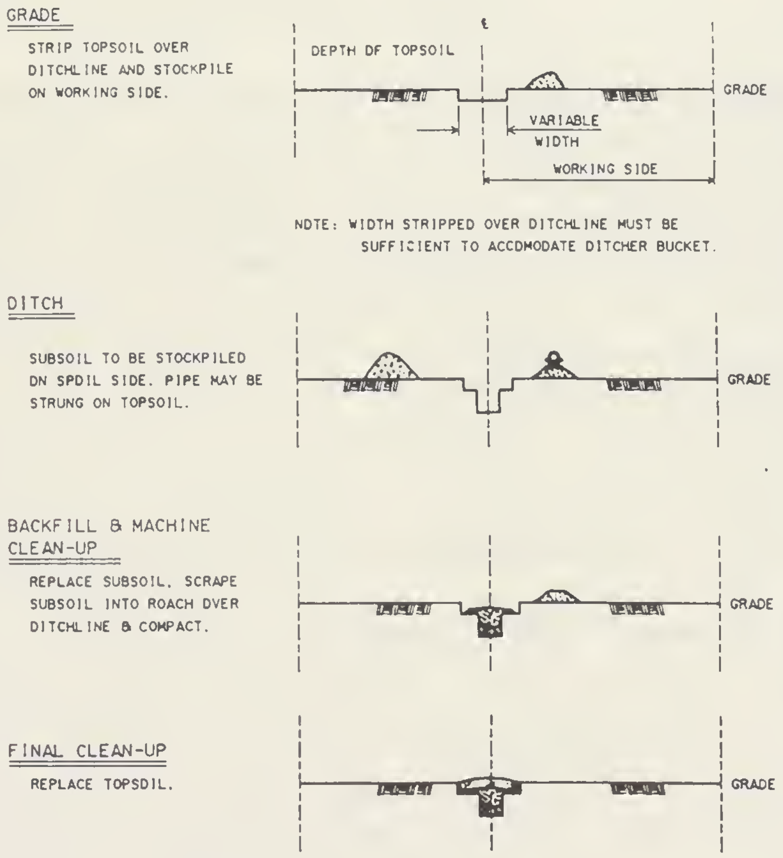
NOTES

1. EXCAVATE TOPSOIL AND SUBSOIL AS A SINGLE LIFT. PLACE TRENCH SPOIL ON SPOIL SIDE ADJACENT TO TRENCH.

2. RETURN TRENCH SPOIL TO TRENCH AND COMPACT. MINIMIZE SCALPING OF UNDISTURBED SOD LAYER IN GRASSED LANDS. LEAVE A ROACH OVER THE TRENCH TO ALLOW FOR SUBSIDENCE.

3. RESEED WITH A COMPATIBLE SEED MIX AND FERTILIZE.

Figure 1: No topsoil stripping procedure in summer conditions (Alberta Environment 1985).



GRADE

STRIP TOPSOIL OVER DITCHLINE AND STOCKPILE ON WORKING SIDE.

NOTE: WIDTH STRIPPED OVER DITCHLINE MUST BE SUFFICIENT TO ACCOMODATE DITCHER BUCKET.

DITCH

SUBSOIL TO BE STOCKPILED ON SPOIL SIDE. PIPE MAY BE STRUNG ON TOPSOIL.

BACKFILL & MACHINE CLEAN-UP

REPLACE SUBSOIL. SCRAPE SUBSOIL INTO ROACH OVER DITCHLINE & COMPACT.

FINAL CLEAN-UP

REPLACE TOPSOIL.

Figure 2: Ditchline stripping procedure in summer conditions (NOVA 1988).

Using blade width stripping, topsoil is stripped and placed adjacent to the trench on the work side of the RoW. Removed subsoil is stored adjacent to the trench on the spoil side of the RoW (Fig. 3).

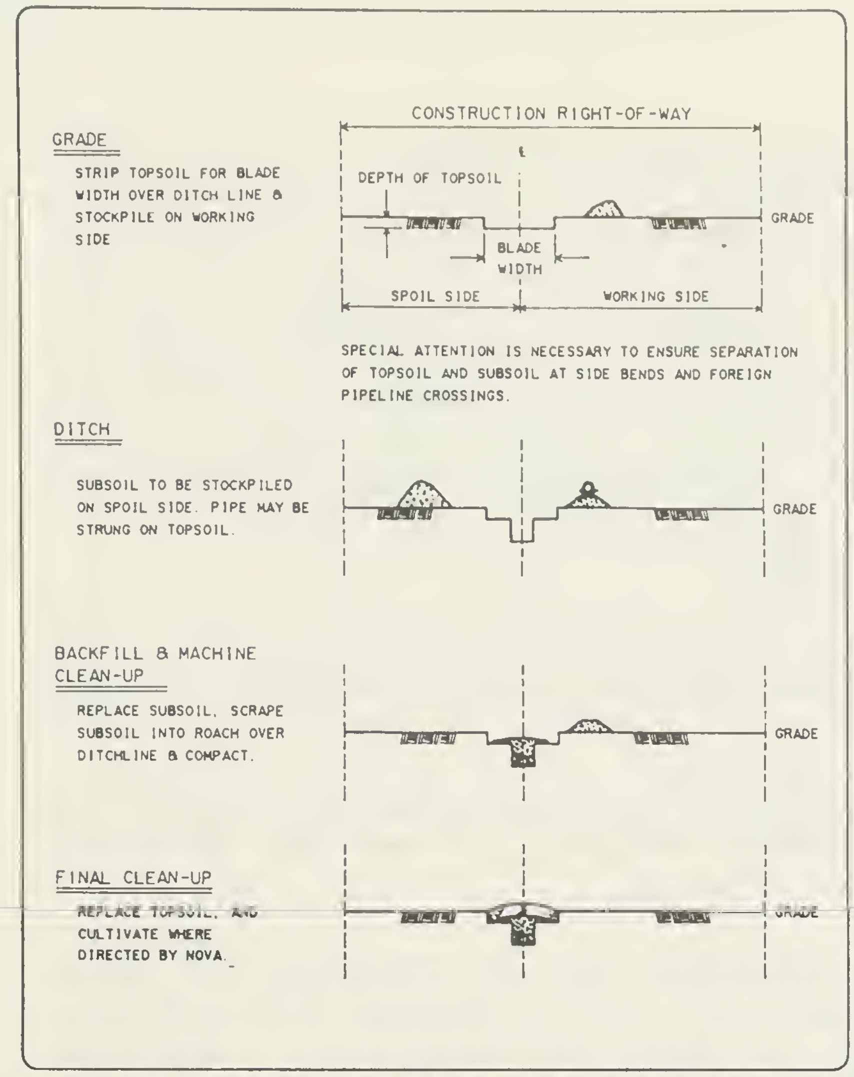
Ditchline and Spoil Side Stripping. This procedure is the most widely used technique for pipeline construction on agricultural lands, specifically cultivated land, sparsely covered pasture and hay lands, and cleared areas that have agricultural potential (Alberta Environment 1985; NOVA 1988). Ditchline and spoil side stripping removes topsoil from the ditchline area plus the entire area allocated for spoil material. Topsoil is then placed on the far side of the spoil side of the RoW (Fig. 4). Excavated subsoil is placed 1 m (3 ft) from the topsoil pile on the area stripped of topsoil. This procedure ensures that topsoil is placed on topsoil and subsoil on subsoil to prevent mixing and loss of topsoil material.

Ditchline, Spoil Side and Work Side Stripping. This stripping technique (full RoW stripping) is used only in: areas requiring grading, potentially arable forested areas, agricultural lands where topsoil depths are thin, and where construction will likely occur in wet weather. With full RoW stripping, topsoil is stripped to the far sides of the RoW and placed on topsoil material (Fig. 5.) Excavated subsoil material is placed on the spoil side of the RoW beside the trench. This procedure ensures that any topsoil material present is not lost through mixing. As well, any compaction which may occur, can be alleviated before topsoil replacement.

WINTER CONSTRUCTION

Ditchline Stripping. With this procedure, the RoW is prepared by removing snow to the edges of the RoW. Topsoil is stripped over the ditchline and placed on the work side beside the ditch (Fig. 6). If the subsoil is not to be excavated immediately, the AGTD's standard procedure is to place a snow roach over the stripped area to prevent ditchline frost penetration (NOVA 1988). If conditions are such that the topsoil on the spoil side of the RoW is not frozen, the topsoil is graded off to the spoil side edge, just in front of the ditching operation to avoid potential loss during backfill. Excavated subsoil is then placed on a hard, smooth surface and kept separate. Topsoil is replaced the following summer after the replaced spoil has thawed and settled.

The two types of equipment used for stripping topsoil in winter are the modified ditching wheel and the AGTD's adjustable step-blade with a ripper. The AGTD's adjustable step-blade performs well in border line frost conditions, but it may also be used during full frost if the topsoil is not too deep or if the area is "ripped". To perform winter stripping, replaceable ditcher teeth are welded to the cutting edge to help the step-blade cut into the frost (NOVA 1988).



GRADE

STRIP TOPSOIL FOR BLADE WIDTH OVER DITCH LINE & STOCKPILE ON WORKING SIDE

SPECIAL ATTENTION IS NECESSARY TO ENSURE SEPARATION OF TOPSOIL AND SUBSOIL AT SIDE BENDS AND FOREIGN PIPELINE CROSSINGS.

DITCH

SUBSOIL TO BE STOCKPILED ON SPOIL SIDE. PIPE MAY BE STRUNG ON TOPSOIL.

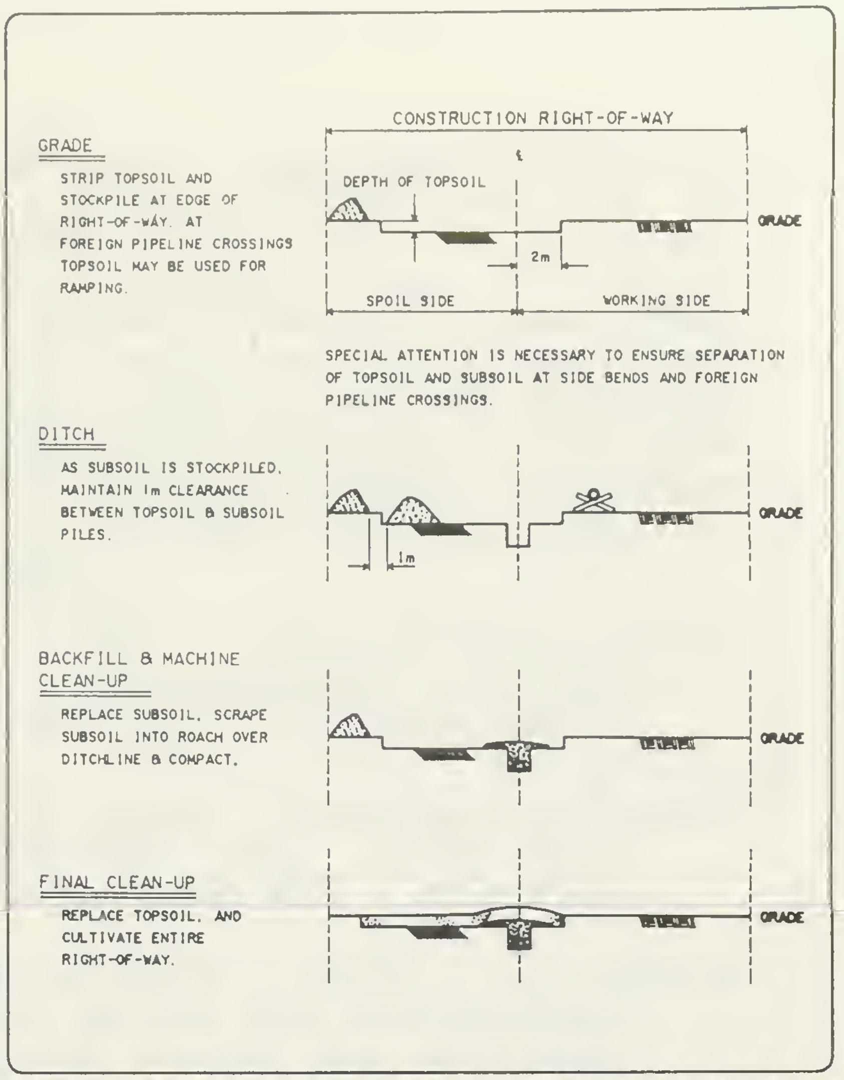
BACKFILL & MACHINE CLEAN-UP

REPLACE SUBSOIL, SCRAPE SUBSOIL INTO ROACH OVER DITCHLINE & COMPACT.

FINAL CLEAN-UP

REPLACE TOPSOIL, AND CULTIVATE WHERE DIRECTED BY NOVA.

Figure 3: Blade width stripping procedure in summer conditions (NOVA 1988).



GRADE

STRIP TOPSOIL AND STOCKPILE AT EDGE OF RIGHT-OF-WAY. AT FOREIGN PIPELINE CROSSINGS TOPSOIL MAY BE USED FOR RAMPING.

SPECIAL ATTENTION IS NECESSARY TO ENSURE SEPARATION OF TOPSOIL AND SUBSOIL AT SIDE BENDS AND FOREIGN PIPELINE CROSSINGS.

DITCH

AS SUBSOIL IS STOCKPILED, MAINTAIN 1m CLEARANCE BETWEEN TOPSOIL & SUBSOIL PILES.

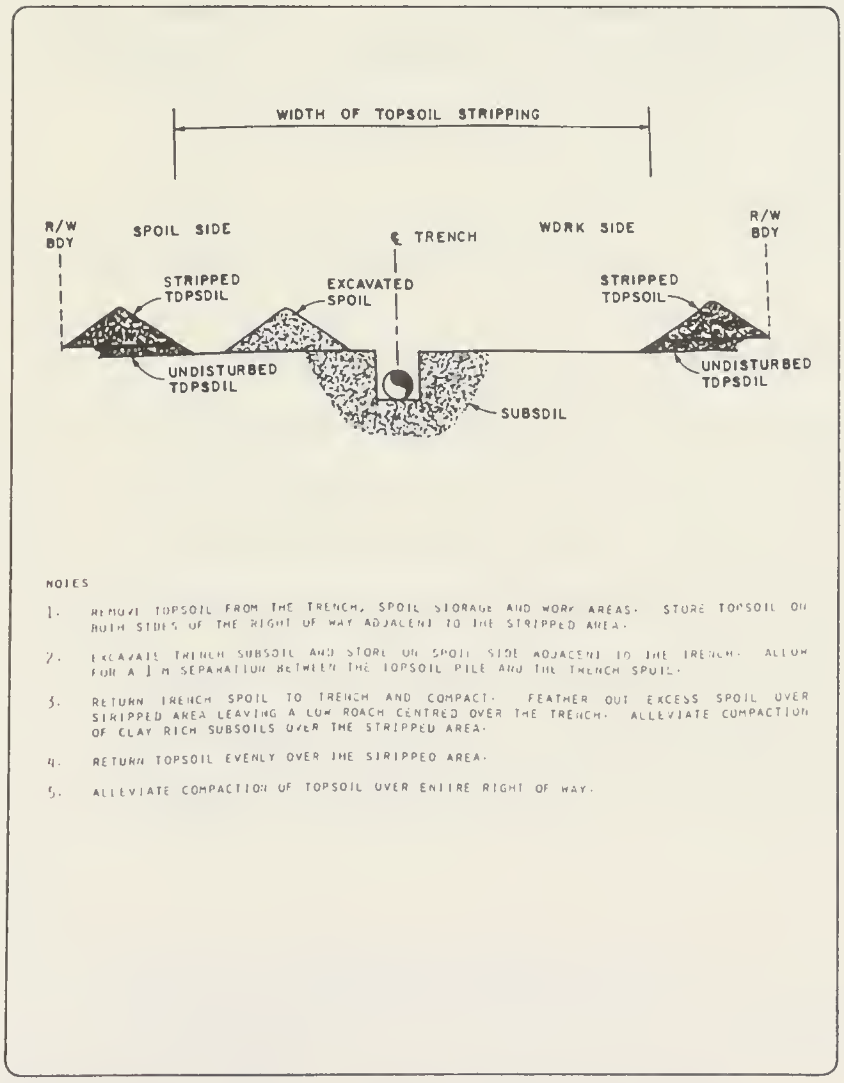
BACKFILL & MACHINE CLEAN-UP

REPLACE SUBSOIL, SCRAPE SUBSOIL INTO ROACH OVER DITCHLINE & COMPACT.

FINAL CLEAN-UP

REPLACE TOPSOIL, AND CULTIVATE ENTIRE RIGHT-OF-WAY.

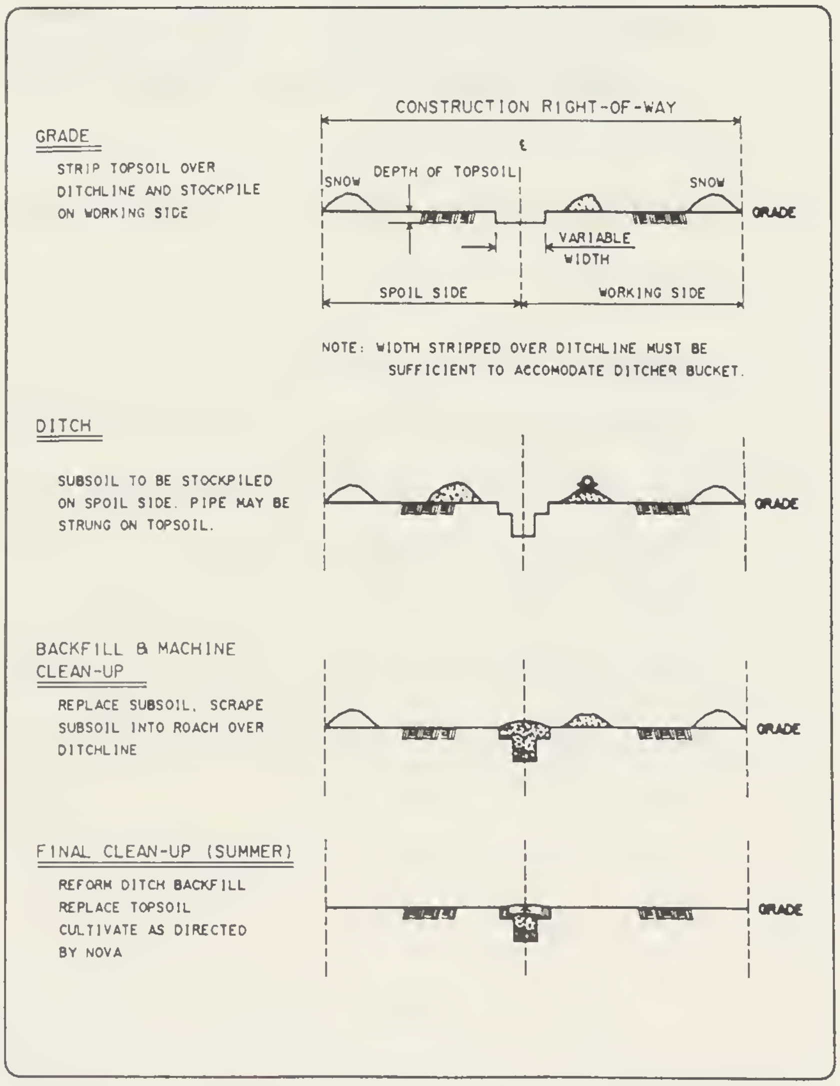
Figure 4: Ditchline and spoil side stripping procedure in summer conditions (NOVA 1988).



NOTES

1. REMOVE TOPSOIL FROM THE TRENCH, SPOIL STORAGE AND WORK AREAS. STORE TOPSOIL ON BOTH SIDES OF THE RIGHT OF WAY ADJACENT TO THE STRIPPED AREA.
2. EXCAVATE TRENCH SUBSOIL AND STORE ON SPOIL SIDE ADJACENT TO THE TRENCH. ALLOW FOR A 1 M SEPARATION BETWEEN THE TOPSOIL PILE AND THE TRENCH SPOIL.
3. RETURN TRENCH SPOIL TO TRENCH AND COMPACT. FEATHER OUT EXCESS SPOIL OVER STRIPPED AREA LEAVING A LOW ROACH CENTRED OVER THE TRENCH. ALLEVIATE COMPACTION OF CLAY RICH SUBSOILS OVER THE STRIPPED AREA.
4. RETURN TOPSOIL EVENLY OVER THE STRIPPED AREA.
5. ALLEVIATE COMPACTION OF TOPSOIL OVER ENTIRE RIGHT OF WAY.

Figure 5: Trench, spoil and work side stripping procedure in summer conditions (Alberta Envirnoment 1985).



GRADE

STRIP TOPSOIL OVER DITCHLINE AND STOCKPILE ON WORKING SIDE

NOTE: WIDTH STRIPPED OVER DITCHLINE MUST BE SUFFICIENT TO ACCOMODATE DITCHER BUCKET.

DITCH

SUBSOIL TO BE STOCKPILED ON SPOIL SIDE. PIPE MAY BE STRUNG ON TOPSOIL.

BACKFILL & MACHINE CLEAN-UP

REPLACE SUBSOIL, SCRAPE SUBSOIL INTO ROACH OVER DITCHLINE

FINAL CLEAN-UP (SUMMER)

REFORM DITCH BACKFILL
REPLACE TOPSOIL
CULTIVATE AS DIRECTED BY NOVA

Figure 6: Ditchline stripping procedure in winter conditions (NOVA 1988).

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No Topsoil Stripping. As with summer construction, certain areas may not accommodate topsoil stripping in winter. No topsoil stripping is considered after an assessment of the following criteria: topsoil depth, stoniness, soil chemistry and land use (NOVA 1988). The AGTD considers it impractical to conserve topsoil where depths are less than 10 cm (4 in). In rocky or treed areas, machinery may not operate efficiently and may have an inordinate amount of downtime for repairs. Tree roots may also become entangled in the stripping machine and interfere with progress.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

THE IMPACTS OF GRAZING REGIME ON REVEGETATION AFTER PIPELINE CONSTRUCTION IN A CANADIAN MIXED PRAIRIE ECOSYSTEM

M.A. Naeth[1]

ABSTRACT

A study was conducted in native mixed prairie rangeland of southern Alberta, Canada to evaluate vegetative responses to pipeline installation under early and late season grazing. Sites were selected in a pipeline corridor containing pipelines that had been installed in 1957, 1963, 1968, 1972, and 1981. At each site, plant species composition, frequency, basal area, and ground cover characteristics were assessed in different construction zones of each pipeline right-of-way.

Botanical composition of the right-of-way was significantly altered by pipeline construction. Following disturbance, pioneer and introduced species dominated the right-of-way, particularly over the trench. On older pipelines there was evidence of succession towards native mixed prairie vegetation. Changes in vegetative factors due to pipeline construction were compounded by the grazing regime imposed on the system. It was concluded that successful revegetation after pipeline construction requires an effective range management program to expedite a stable, erosion-reducing ground cover compatible with the functioning of a native mixed prairie ecosystem.

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INTRODUCTION

Successful rangeland reclamation and revegetation associated with industrial disturbances requires a knowledge of grazing impacts on the ecosystem. When selecting plant species for rangeland revegetation, not only resistance to grazing but the effect of season of defoliation must be considered. Grazing impacts on the hydrology of an ecosystem must also be considered (Naeth 1988). Industrial disturbances will cause more problems on overgrazed rangelands than on less heavily grazed rangelands.

Revegetating native rangelands after linear disturbances creates a specific problem. Cattle are attracted to the right-of-way (r-o-w) with lush growth that is more palatable and productive than native range, particularly if it is fertilized (Naeth 1985). R-o-w species are often later maturing and more palatable when native species have set seed. Rangeland cattle tend to move onto the r-o-w when they enter the field each spring. This attraction leads to excessive defoliation which can reduce plant cover from the r-o-w if young seedlings are grazed in spring before they can develop a sufficient root system or carbohydrate reserves to resist grazing. Cattle overuse of the r-o-w is associated with trampling and compaction of the soil surface which can lead to crusting and sealing resulting in reduced infiltration capacity, and associated runoff and erosion. Litter is often removed during pipeline construction and is not built up for many years if the r-o-w is grazed. It is important to identify potentially detrimental grazing regimes so revegetation strategies can be adapted to the grazing regime or the grazing regime altered until a suitable ground cover has been established.

The data presented are from a study that assessed effects of early and late season grazing on revegetation after pipeline construction within different zones of construction activity and on different aged pipeline r-o-w.

MATERIALS AND METHODS

Study Site Description

Four study sites were located in mixed prairie within a natural gas pipeline corridor approximately 225 km east of Calgary, Alberta, Canada (51 °N latitude and 112 °W longitude). Sites were located within 4 km of each other. The area has a continental prairie climate and semiarid moisture regime. Mean annual precipitation is 355 mm with an average annual moisture deficit of 227 mm. Mean annual temperature is 4 °C, with a July mean of 19 °C and a January mean of -14 °C. Elevation averages 745 m above sea level with slopes of less than 2%.

Soils are Brown Solodized Solonetz and Brown Solod developed on till (Kjearsgaard et al. 1982). Eroded pits (blowouts), where the A horizon was lost by wind erosion, are common. Undisturbed prairie soil to a 7.6 cm depth was silt loam to loam textured (Naeth et al. 1987). Soil texture to 45 cm in the 1981 trench was clay loam and in all other treatments was loam. Soil texture below 45 cm in all treatments was clay loam. Surface bulk density was lowest in undisturbed prairie (0.97 Mg m^{-3}) and highest in the 1981 trench (1.6 Mg m^{-3}) (Naeth et al. 1987). Bulk density decreased with depth in the 1981 trench but increased with depth in the other treatments.

Vegetation is of the Blue grama-Spear grass-Wheat grass (*Bouteloua-Stipa-Agropyron*) faciation dominated by blue grama (*Bouteloua gracilis*), spear grass (*Stipa comata*), western and northern wheatgrasses (*Agropyron smithii* and *dasystachyum*)(Coupland

1961). Pasture sage (*Artemisia frigida*) and little club-moss (*Selaginella densa*) are common forbs. A short grass disclimax dominated by blue grama is common as a result of heavy long-term grazing.

Two grazing treatments were studied within a community pasture established in 1964: (1) early season grazing from May 1 through July; and (2) late season grazing from August through October. The 0.9 AUM ha^{-1} stocking rate was considered heavy for the area. Two sites were early season grazed and two were late season grazed.

Each site was 100 by 135 m, spanning five r-o-w with an undisturbed (control) area on either side (Figure 1). Pipelines ranged in diameter from 86 to 107 cm and were installed in 1957, 1963, 1968, 1972, and 1981. Sites were divided into treatment strips representing different areas of pipeline construction activity and ages of pipeline r-o-w. The 1981 r-o-w was 30 m wide and comprised the stockpile; the trench; the pipelay, approximately 3 m from the center of the 1981 trench, where pipe was strung until installation; and the work area, approximately 10 m from the center of the 1981 trench, over which most vehicular movement occurred. The area corresponding to work, pipelay, and stockpile treatments of the older r-o-w was referred to as the between trenches treatment.

The 1981, 1972, and 1968 r-o-w were seeded to mixtures of introduced species: *Agropyron pectiniforme* (crested wheatgrass), *Elymus junceus* (Russian wildrye), *Agropyron riparium* (streambank wheatgrass), *Agropyron trachycaulum* (slender wheatgrass), *Agropyron elongatum* (tall wheatgrass), *Agropyron trichophorum* (pubescent wheatgrass), *Elymus angustus* (Altai wildrye), *Medicago* species (alfalfa), *Onobrychis vicaefolia* (sainfoin), and *Astragalus cicer* (cicer milk-vetch). The 1957 and 1963 r-o-w were not seeded.

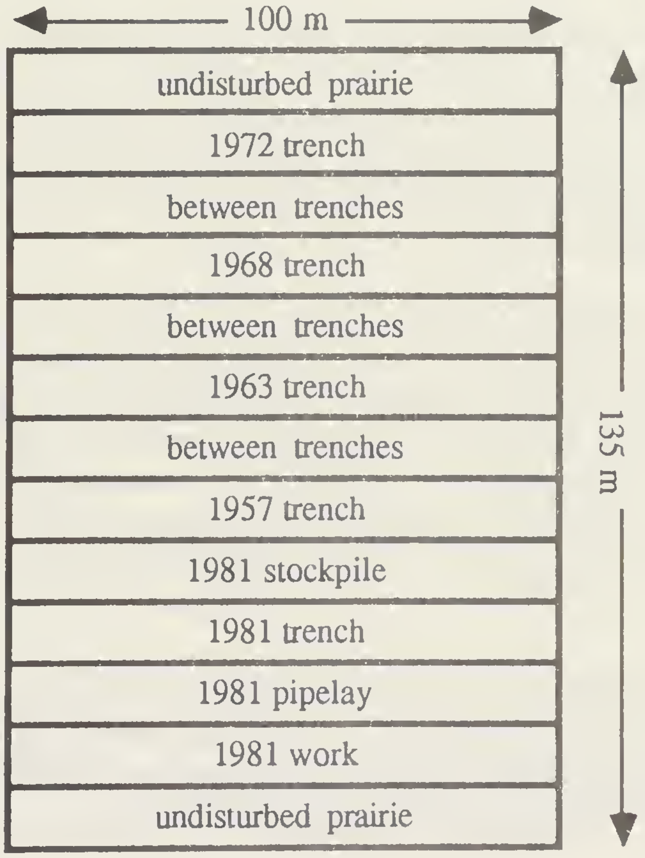

Figure 1. Site treatment strip layout.

Data Collection and Analyses

One hundred 0.1 m^2 (20 x 50 cm) quadrats were read in each treatment, in 1982 and 1983. Ocular estimates of basal area were made for individual species, bare ground, live vegetation, and litter. Frequencies of each species were recorded. On the 1981 r-o-w twenty-five 1.0 m segments were randomly selected among each of four seeded rows, and introduced and native plants were counted to determine plant density.

The experimental design consisted of four blocks (sites or replicates) each containing all treatment strips. Because of the nature of the pipelines, physical arrangement of treatments within each block was the same. Data were tested for homogeneity of variance with Cochran's test. Chi square was used to test departure from expected values and determine homogeneity of species with respect to frequency and cover (Steel and Torrie, 1980).

RESULTS

The native prairie on either side of the r-o-w was considered an undisturbed treatment since pipeline construction activities did not affect it. It was used to assess grazing impact. Under early season grazing, there was more bare ground and less live vegetation and litter than under late season grazing. If late season grazed, vegetation was more desirable in composition with one-third less moss (*Selaginella densa*), two-thirds more grass and one-third more forbs. Native prairie vegetation was dominated by *Selaginella densa*, which had a basal area over 68%. Dominant grasses were *Bouteloua gracilis*, *Koeleria macrantha*, *Agropyron* species, and *Stipa* species. Forbs were abundant, predominantly *Artemisia frigida* (pasture sage), *Phlox hoodii* (moss phlox), *Opuntia polyacantha* (prickly pear cactus), and *Sphaeralcea coccinea* (scarlet mallow). Sedges were abundant and shrubs were few. Over 99% of the species were native.

Pipeline construction changed botanical composition and ground cover significantly. Trenching was most destructive compared to grading and stockpiling operations. Immediately after pipeline construction in 1981 live vegetation comprised 0.0% of ground cover over the trench and approximately 5% over the rest of the r-o-w. Species on the 1981 r-o-w had very low frequencies and over 95% had basal areas of less than 10%. By 1982 vegetative cover over the trench increased to 5%.

Ground cover in 1983 reflected the superimposed grazing disturbance with live vegetation over the 1981 trench twice as high under late season grazing (6%) as under early season grazing (3%). Other areas of the 1981 r-o-w were similarly affected by grazing. There were few differences in live vegetation related to grazing on the oldest trench but there were still significantly higher values for bare ground and lower values for litter under early season grazing. Basal area of live vegetation also reflected grazing impacts with values consistently higher under late season grazing than under early season grazing in all treatments.

Plant density of native species was consistently higher under late season grazing than under early season grazing; six times higher in the work area, twice as high in the pipelay area, three times higher over the trench, and three times higher in the stockpile area. Density of introduced species was less dramatically affected by grazing regime.

The effect of grazing on revegetation is most obvious when examining frequency and basal area of *Agropyron pectiniforme* and *Descurainia sophia* (flixweed). *Agropyron pectiniforme* dominated the 1968 and 1972 r-o-w (99%) under late season grazing but was only a minor component of the vegetation under early season grazing (less than 10%). No other introduced species persisted and native species invasion had been accomplished by only a few ruderals. *Agropyron pectiniforme* was a dominant species under both grazing regimes immediately after pipeline construction but was decreasing under early season grazing within a year. In 1982, *Descurainia sophia* dominated the 1981 r-o-w under late season grazing (80% frequency), but under early season grazing the species was a relatively minor component of the vegetation (2% frequency).

In all sites, species composition of the 1957 r-o-w was not significantly different from the undisturbed prairie. Under early season grazing, the 1963, 1968, and 1972 r-o-w were more similar in botanical composition to the 1957 r-o-w than to the 1981 r-o-w or the undisturbed prairie. Under late season grazing, these transects were significantly different from all other transects.

DISCUSSION

More introduced species and more species with lower basal areas and frequencies on the trench compared to the other treatments reflects the more hospitable conditions after grading for regrowth from species with intact or partially buried roots. Higher basal areas and frequencies for many species and more native species under late season grazing reflect the susceptibility of some species to early season grazing. Most species present are cool season and begin growth in late March or early April, are heading or flowering in June, have completed seed maturation by July and by August will be dormant or cured. These cool season species will be most affected by early season grazing. Severe defoliation during early stages of phenological development can be detrimental to seed production and thus species survival. Species that reproduce vegetatively are stunted after severe defoliation because energy must be put into rebuilding photosynthetic parts and carbohydrate reserves necessary for winter survival.

Early maturing species that are late season grazed have a distinct advantage for survival over those that are early season grazed. By July and August, most early maturing species are entering summer dormancy and are more resistant to grazing. Some species, such as those of the *Stipa* genus, have prickly unpalatable seeds. *Agropyron pectiniforme* is also coarse and unpalatable. Many forbs are declining in vigor, maturing seeds, or have already cured by the time late season grazing begins. Thus only later maturing species and those that experience autumn regrowth will be sensitive to grazing at this time. Grazing in late autumn will detrimentally affect species which have not built sufficient carbohydrate reserves for winter survival, and species reproducing from seed, whose seed matures late in the season. With late season grazing, native species on the work and stockpile areas could partially recuperate from disturbance. Species in early season grazed sites would be defoliated and trampled when at peak vulnerability because of low energy reserves. Thus many weedy species would not survive if early season grazed whereas those that were late season grazed would have time to recover from pipeline construction before being subjected to grazing. The trench was the most severely disturbed and would take longer to recover. Native plant roots and seeds were not on the trench and only introduced seeds were present. Introduced seeds are often planted late in the season and would not germinate as readily as the plants that were already present on the other transects would recuperate, thus accounting for the smaller number of plants over the trench.

The 1968 and 1972 r-o-w were seeded to a mixture with *Agropyron pectiniforme* during the final stages of pipeline construction. *Agropyron pectiniforme* generally does not suffer frost damage nor winter kills and is highly drought resistant due to its extensive rooting system. It is also an excellent weed competitor. These characteristics make it a species well suited to eventual dominance of a disturbed area. Studies involving *A. pectiniforme* on mixed prairie indicated that when it was grazed early in the spring native dominants expanded and competed successfully (Hubbard 1949).

The 1981 r-o-w treatments were dominated by introduced and native invaders, or weedy species. The older pipeline r-o-w had more native species, with loss of dominance by introduced species. With time, disturbed areas appear to be approaching the vegetative character of the undisturbed transects, but here are still significant differences in botanical composition.

If the basal area of *Selaginella densa* is taken into consideration, then undisturbed live vegetation provided by other species is similar to those for all disturbed transects. Since *Selaginella densa* is unpalatable, the productivity of the area may not be dramatically reduced by pipeline construction except over the 1981 r-o-w. Within 15 years live vegetation over the trenches has returned to near pre-disturbed conditions. Other transects of the r-o-w appear to approach these conditions within 10 years. Thus it appears there is a fairly rapid return to predisturbed levels of palatable forage under proper grazing. From a soil conservation perspective, *Selaginella densa* provides protection from erosion. The time required for *Selaginalla densa* to invade after pipeline construction is unknown. If many years are required, perhaps erosion protection would be provided by increased cover from the more palatable species that could increase in basal area under proper range management, making the presence of *Selaginella densa* unnecessary from a conservation perspective and undesirable from a livestock grazer's view.

CONCLUSIONS

Pipeline construction activities and line operation have a profound effect on the rangeland ecosystem. The most obvious effect is the reduction or removal of vegetative cover over the r-o-w. The grazing regime imposed on rangeland affects vegetative characteristics and thus affects reclamation efforts.

Although grazing slows revegetation progress, if properly managed, it can be used to aid in weed control and enhance revegetative efforts without the detrimental economical implications of no grazing.

Early season grazing reduces weeds that readily colonize disturbed areas. However, this grazing regime decreases vegetative cover and increases bare ground which has serious consequences in soil erosion. *Agropyron pectiniforme* is desirable and capable of increasing native range productivity. But it must be grazed early in the seaon to ensure palatability yet not grazed so long at a high intensity that it is eliminated. Reducing both stocking rate and grazing period for the first few years following revegetation would be beneficial. Rotating the grazing seasons can also assist in vegetation management after pipeline construction.

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CONSTRUCTION MANAGEMENT - THE KEY TO SUCCESSFUL RECLAMATION

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ABSTRACT

Successful reclamation begins at the time of the initial project proposal. For surface disturbing activities proposed on public lands, environmental documentation in compliance with the National Environmental Policy Act (NEPA) is the key step in determining the preferred alternative.

Detailed project design proceeds based on the original proposal as modified during NEPA compliance and guided by environmental concerns and mitigating measures resulting from NEPA documentation.

The investment in time and money to complete proposals, NEPA compliance, and detailed design is compromised unless sound procedures for project management and, specifically, construction control are established up front.

During development of the Exxon LaBarge Project in southwest Wyoming, a "self-monitoring" construction control procedure has been jointly developed by industry and public land management agencies. This approach proved highly successful in implementing the project's "design for reclamation" philosophy and serves as a successful demonstration project for management of large proposals in sensitive environments.

This paper describes the self-monitoring system utilized, provides an overview of the LaBarge Project parameters, and presents an analysis and summary of the results. Experience with the LaBarge Project confirms the importance of comprehensive project planning/design coupled with sound project management and construction control procedures. The foundation for design/construction is interactive use of NEPA (environmental) documentation.

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INTRODUCTION

Problem Statement

Projects proposed and authorized on public land vary widely in scope and complexity but share one thing in common; they require a substantial investment in location, design, National Environmental Policy Act (NEPA) compliance and formulation of conditions of approval (stipulations). The value of this investment, by both government and industry, is compromised if construction of the facility does not comply with the approved design.

In the past, significant projects have been permitted with insufficient attention to plans and monitoring of construction for compliance. Noncompliance may mean failure to comply with key requirements of decision documents generated from Environmental Impact Statements (EIS) or Environmental Assessments (EA). In real terms, this can mean the difference between a reclaimable temporary disturbance and a long term adverse impact, particularly in sensitive areas (e.g. unstable soils, riparian environments, steep terrain).

Lack of proper construction control is, all too often, the missing link in the steps toward a properly constructed project on public lands. Construction control is that important process of defining the approved plan on the ground, (via construction survey and staking), coupled with a follow-up compliance monitoring program.

The Solution Starts with a Plan

To build something ... anything, you first need a plan. Public land management agencies are evolving away from approvals based on narrative project descriptions and long lists of conditions of approval, in favor of actual construction plans and drawings which more clearly define the project and reduce the number of stipulations. BLM's "Rights of Way Handbook" (BLM, 1984) for example, was a major step in the right direction. For the first time, significant program-wide guidance recognized that a "picture is worth a thousand words." Regardless of the proposal, the Handbook emphasizes "plans of development" (POD). Theoretically, use of the POD can result in the reduction of an extensive list of conditions to a simple one: "Your plan is approved. Follow your approved plan." In practicality, the POD concept can at least, significantly reduce government imposed conditions and place emphasis on the information contained in the project proposal.

The Rights of Way Handbook recognized that the level of detail of a POD must be consistent with the complexity of the project proposed. A POD may range from a simple narrative project description and map to detailed design plans and specifications. The extent of the POD is left to the judgment of the field specialist and manager. Regardless of detail, the plan describes something to be built on the ground.

The Plan is Only as Good as Its Execution

Historically, the weakest step in the process has been lack of communication of the approved project proposal to the contractor hired to build it. At this stage, the project already represents a substantial dollar and time investment by both the project proponent and the government. It is here that the investment is either properly carried to completion or compromised (even wasted in extreme cases).

During 1985-86, an alternative approach to construction control was implemented in western Wyoming on Exxon's LaBarge Project. This alternative to traditional BLM compliance methods proved effective and is described as follows:

EXXON LABARGE PROJECT

(Review/Analysis of an Industry Self-Monitoring Program)

Background

Exxon's LaBarge Project, located in Sublette and Lincoln Counties in western Wyoming, involved development of a deep gas field (14,000 to 18,000 foot wells) located primarily on lands administered by the Forest Service (FS) and Bureau of Land Management (BLM). Twenty-one gas wells, 3 manifold sites, 39 miles of gathering lines and water lines (multiple pipelines), a dehydration facility, a 39-mile sour gas (hydrogen sulfide) trunkline, a gas conditioning plant, 93 miles of access road (new and reconstructed) and 51 miles of powerline were constructed within or in the vicinity of the well field area. Development drilling activity and limited site construction began in 1984; however, the bulk of well field construction activity occurred between May and November 1985. The project was substantially completed by September 1986.

Construction, operation, and reclamation of the project was governed by the Riley Ridge Final Environmental Impact Statement (FEIS) and Record of Decision (ROD) (BLM/FS, 1983/84). Prior to beginning construction, Exxon submitted and received approval of overall Construction and Use Plans and site-specific plans, which collectively constituted a complete Plan of Development. Standard field construction survey control governed earthwork activities. The project was controlled by Exxon personnel on-site and in Midland, Texas, and permitting and plan approval was conducted by the Bridger-Teton National Forest Supervisor's Office, and Big Piney Ranger District, and BLM's Pinedale Resource Area and Rock Springs District.

Self-monitoring of project activities occurred through an organized Quality Assurance/Quality Control program.

What is Quality Assurance/Quality Control?

The Quality Assurance/Quality Control (QA/QC) concept is not new. QA/QC has been widely used as construction management tool in industrial and major construction project applications for several years. The concept depends on advance development of plans and specifications governing the work, followed by systematic monitoring of construction activities. The separate but related responsibilities of QA and QC are as follows:

Quality Control - QC is directly responsible for ensuring that project activities are conducted in accordance with approved specifications and plans. Typically, each major construction operation is observed by a QC Inspector. QC Inspectors are in the general vicinity of their assigned operation on a full-time basis and are charged with determining whether the contractor is in compliance with specifications, procedures, etc. If noncompliance occurs, the QC Inspector takes immediate action instructing the contractor to correct the deficiency. Noncompliance is documented via noncompliance reports (NCR) or, at a minimum, in the QC Inspector's daily log or diary.

Quality Assurance - QA is responsible for determining that the project's QC system is effectively operating to ensure compliance. Typically, the QA Inspector accomplishes this through periodic on-site visits to the various construction sites, audit review of QC records, and dialogue with QC Inspectors. If QA review identifies any problems with the QC system, they are documented and brought to the attention of the Chief QC Inspector for correction. On a typical project, one QA Inspector may cover the same scope of work activity as 10-20 QC Inspectors. To be effective and credible, the QA function must be organizationally independent from, but closely coordinated with, the QC system. QC operates in a daily on-site monitoring mode while QA's role is typically one of systems review/analysis and record audit. Together the two form a coordinated project monitoring and oversight function keeping project management personnel informed of the project's progress and overall quality.

The LaBarge Project Quality Assurance/Quality Control Program

Between November 1984 and April 1985, meetings were held between Exxon, FS, and BLM to determine the most efficient method of handling the peak permit and construction workload anticipated during the 1985 construction season. Expeditious permit processing was needed to support an aggressive construction schedule and a sound construction control program was required to insure that field work complied with approved plans. Field compliance was considered critical due to the magnitude of the project development and the sensitive nature of the project area. Based on general guidelines provided by BLM and FS, Exxon designed a self-monitoring program which was approved by the federal agencies. This program consisted of a comprehensive industry QA/QC Program with federal oversight.

Exxon's 1985 QC Program consisted of 58 inspectors under the direction of 15 Field Construction Coordinators and Technical Foremen. These QC personnel were responsible for direct inspection of construction activities to ensure compliance with approved plans and specifications. QA was staffed by 5 inspectors under the supervision of a Compliance Engineer. The primary responsibility of QA personnel was to monitor the QC program and provide general oversight to the project with emphasis on environmental considerations. Staffing of the QA/QC program was provided by Exxon and consisted primarily of personnel contracted from various consulting firms in the region.

To interact with Exxon's QA/QC staff in the field, the FS and BLM jointly appointed two Authorized Officer's Representatives (AORs). The AORs (one from each agency) provided seven day coverage of the project on a rotating schedule. The AOR's jurisdiction covered the entire well field and feed gas pipeline without regard for the administrative boundary between BLM and FS lands. The primary role of the AOR team was to oversee the effectiveness of Exxon's QA/QC program and to act on field modifications to approved plans. AOR personnel were delegated responsibility to approve field changes and judge when contact with the appropriate Authorized Officer was required.

The Results

Between May 1985 and January 1986, 6 well sites, 3 manifold sites, 39 miles of multiple string pipeline, 49 miles of road (new and reconstructed), and 39 miles of powerline were constructed in the well field. In addition, the 39 mile feed gas trunkline was substantially completed including construction of 9 miles of permanent access road and 11 pipeline block valves. During the same period, reclamation work was performed on over 1,400 acres of temporarily disturbed lands. This activity required approval of approximately 120 field design modifications.

The experience with the 1985 construction season clearly demonstrated the value of the QA/QC concept as described above. Overall, the system worked effectively and allowed for industry self-compliance with minimal federal involvement in the field. AOR's, as the focal point for field contact with Exxon, provided clear, consistent federal input to the process of construction control. By assuming the responsibility for their own compliance and construction control, Exxon enabled the BLM and FS to handle the massive LaBarge Project without hiring additional personnel. During 1986, the program continued intact with gradual reduction in personnel proportional to the level of field activity. Again, the system proved its value and the project was substantially completed by September 1986.

Analysis of the QA/QC Program

Due to the potential value of Self-monitoring the QA/QC concept for other projects on public lands, a "post season" review of the system was conducted. The review was based on interviews and reports prepared by the AORs, contact with other BLM and FS personnel involved with the project and interviews with Exxon personnel and consultants employed in both QA and QC functions on the LaBarge Project.

Based on the above, the following conclusions were evident:

1. The use of a self-monitoring program of this type is valid for large projects such as the LaBarge Project.

2. Success of the concept depends on advance support and commitment by management (both government and industry).

3. The effectiveness of the concept and, to a greater degree, specific activities conducted under this system is directly dependent on the backgrounds, personalities, and qualifications of the individuals involved.

4. The independence of the QA staff relative to the construction organization is an important factor.

5. The concept shows applicability, in modified form, to virtually all proposals for mineral or land development within federal jurisdiction. The benefits of self-monitoring, however, generally increase with project size and complexity and the environmental sensitivity of the project area.

Details of the above conclusions are discussed below:

1. Use of QA/QC and self-monitoring on large projects:

   The use of QA/QC and its many benefits (both in terms of efficiency and promoting user responsibility for field activities) were clearly demonstrated on the LaBarge Project. This approach minimized the number of agency personnel needed in the field and allowed the BLM and FS to handle the workload of this major project without additional personnel. Government field representatives not only provide project oversight but are available to respond to needs for minor field modifications as they occur.

2. Management support is essential:

   The self-monitoring concept can only succeed if management is committed to the approach and supportive of the personnel involved. Authorized Officers must be willing to trust the judgment of personnel in the field and the project proponent's management must be committed to compliance and self-monitoring. This commitment necessarily includes willingness to alter or even temporarily shut down certain project operations if serious or chronic noncompliance or field conditions require.

3. The concept depends on the people involved:

   Successful implementation of QA/QC self-monitoring is directly dependent on the background, qualifications and personalities of QA, QC and regulatory personnel. Inspection personnel should be experienced in construction and/or project management. Use of the concept will generally make qualified personnel more readily accessible since, 1) experienced personnel are commonly available in the private sector through consultants, and 2) few federal personnel are required to interface with the company's QA/QC organization. This latter point allows Authorized Officers to utilize their most experienced people to handle large projects or several small operations.

4. The importance of QA organizational independence:

   A credible, effective QA/QC system depends on the organizational independence of the QA staff assigned to the project. If both QA and QC report to the same field manager, concerns raised by QA can tend to be discounted in favor of progress or economy. An organizationally independent QA staff tends to result in a "checked and balanced" monitoring system.

5. Applicability of the concept to other types of proposals:

The formalized QA/QC system of self-monitoring is primarily applicable to large development projects. The self-monitoring concept, however, shows utility regardless of project magnitude. For smaller projects such as a single well and access road, pipeline or powerline, the monitoring organization may be as small as a single full- or even part-time QC Inspector.

In many cases, self-monitoring can be implemented simply through utilization of industry personnel who otherwise would be on-site. At a pre-work meeting, federal personnel can explain the key environmental/compliance concerns to project management personnel who than act to ensure compliance. A key element of this approach is preparation of an approved plan of development prior to commencement of construction.

Use of the Self-Monitoring Concept

Self-monitoring is not an across-the-board replacement for traditional compliance methods. It is however, an alternative worth considering in selected situations. The concept is applicable to widely varied situations, however, benefits generally increase with project size and complexity and the sensitivity of the project area. Self-monitoring requires advance planning and coordination,giving consideration to the five items described above.

The concept and general guidelines may be proposed and developed by either the government or the project proponent; however, the actual project compliance organization and staffing should be prepared by the proponent. To be successful, continual constructive dialogue between industry and government must take place and major project issues must be resolved quickly.

Finally, the level of compliance effort must be commensurate with the size and complexity of the proposal. A small project may be handled without additional personnel while large projects may require an extensive formal compliance organization.

Preplanning and commitment by both industry and government are the primary requisites to a successful self-monitoring program.

SUMMARY

Industry self-monitoring, whether through a structured QA/QC program for major projects or via a single full- or part-time QC inspector for smaller projects in sensitive areas, presents an alternative to conventional compliance monitoring. It offers the following advantages:

- It promotes compliance. The holder or operator has a stake in and a clear commitment to compliance "up front". The traditional "we-they" relationship between government and the user, if present in the past, is diffused.

- It simplifies accounting and reduces fund transfer amounts on cost reimbursable Rights-of-Way. Project proponents can directly staff the QC(QA/QC on larger projects) organization, thereby reducing the cost reimbursable amount charged by the government for project monitoring.

- Governmental staffing problems for large projects is reduced or eliminated. Private industry, through the use of consultants, contracts or direct hires is better able to cope with the temporary staff increases and subsequent reductions associated with project work.

- The concept is consistent with current government emphasis on:

  - Public land users paying proportionally for their use.
  - Reduction in "big government" bureaucracy.
  - Government agencies being more responsive to clients (example: AORs in the field can respond directly and quickly to needs for minor project modifications).

- It is consistent with current government emphasis on Human Resource Management, Project Pride, or similar efforts. Capable employees are afforded the opportunity to function independently, making decisions for which they are accountable. In addition, the agencies involved can react more positively to the needs of a large segment of their clientele.

In order to realize the advantages of self-monitoring, only minor obstacles must be overcome, namely:

- Advance coordination with and commitment by the project proponent and the Authorized Officer. The process of developing trust, rapport and open communication begins during the early stages of the project proposal.

- Authorized Officers must be willing to entrust field authority to their representatives on a routine basis. Local managers and staff specialists must recognize and accept that other personnel can become involved in getting the approved plans constructed on the ground.

Self-monitoring and the QA/QC system is not a cure-all for field compliance. The approach should not be viewed as a "across the board" replacement for past compliance techniques. Clearly, however, it is a valuable tool worthy of serious consideration. Self-monitoring is a proven alternative available for discretionary use by field management.

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